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Is Resorption of the Temporomandibular Joint Related to Various Orthodontic Treatment Modalities, Dental Characteristics or Craniofacial Form?

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Is Resorption of the Temporomandibular Joint Related to Various Orthodontic Treatment Modalities, Dental Characteristics or Craniofacial Form?

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By

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Abstract

Introduction: Degenerative joint disease (DJD) or condylar resorption (CR) is mildly prevalent in a pre-orthodontic population and theoretically could contribute to jaw pain and skeletal relapse following orthodontic treatment.

Purpose: To determine whether craniofacial form, dental characteristics or particular orthodontic treatment modalities are related to bony condylar degeneration.

Materials and methods: 174 subjects were divided into three groups based on the grade of condylar resorption. 1) moderate-severe condylar resorption, 2) mild condylar resorption and 3) no condylar resorption (as diagnosed from panoramic radiographs). Lateral cephalometric radiographs were traced at initial presentation (T1) and treatment factors were recorded. Groups were compared for differences in skeletal, dental and modalities of orthodontic treatment. Bony condylar change over time was also measured and compared between those with a history of orthognathic surgery and those without.

Results: Cephalometric findings of statistical significance among those with moderate-severe condylar resorption included increased vertical skeletal measurements (increased Y-axis, SN-PP, SN-OP, SN-MP, UFH, MPA, gonial angle, decreased P-AFH% and facial axis), increased overjet, decreased L1-MP, increased NLA, decreased SNA, SNB and maxillomandibular differential when compared to the other groups. Treatment modalities of statistical significance included a history of orthognathic surgery (three-fold relative risk) and increased treatment time.

Conclusions: Results from this study indicate that risk factors for condylar resorption include a dolichofacial type with increased overjet, extended treatment length and orthognathic surgery.

Key words: condylar degeneration, condylar resorption, orthognathic surgery, orthodontic treatment, panoramic radiograph, craniofacial morphology

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Introduction

The temporomandibular joint is the foundation upon which the occlusion is built. The majority of young patients present for orthodontic treatment with healthy joints. Subsequent treatment usually proceeds uneventfully with most patients continuing to be free of problems during and after orthodontic treatment. However, a small percentage of orthodontic patients show evidence of condylar remodeling or resorption following treatment. These patients may have healthy joints prior to treatment but develop condylar resorption during or after treatment.[1] This can have a deleterious effect on treatment outcome and be alarming to the treating orthodontist. Attained Class I occlusion with ideal overjet and overbite can slowly change into Class II malocclusion with increasing overjet and decreasing overbite. An anterior open bite may develop with concordant facial profile changes as the mandible rotates down and back.[2] Severe condylar resorption may progress to the point that a surgical intervention may be necessary to correct the malocclusion and skeletal dysmorphia. If this occurs during the course of orthodontic treatment, the orthodontist may be held responsible by the patient for causing the pathologic condylar change.

Idiopathic condylar resorption (ICR), falls under the initial category of intracapsular or capsular disorders of temporomandibular joint dysfunction (TMD), it is a condition of unknown origin with no consistent or proven inciting event.[3] If a definitive etiology can be established, which can include secondary osteoarthritis, rheumatoid arthritis, lupus erythematosis or other autoimmune diseases, trauma or steroid use, then the label idiopathic that so often accompanies condylar resorption can be excluded, and it then becomes known as progressive condylar resorption (PCR).[3,37] ICR is also referred to in many publications as degenerative joint disease (DJD). DJD may include condylar resorption (CR) of known or unknown etiology.[4]

There are many theories as to how idiopathic condylar resorption really starts. Etiological questions posed in the literature include a reaction to disc displacement (DD) that progresses into an inflammatory and resorptive state with time,[3] or primary risk factors including certain skeletal characteristics or systemic factors which some patients possess in greater quantity than others thereby may triggering a negative condylar response.[7,8,9,10] Hormone or gender-related factors have been mentioned in the literature,[11,12,13,96] as well as clinician-induced CR. The latter may be occurring from orthodontic treatment and orthognathic surgery or may have a multifactorial etiology.[10,11,13] A concern for clinicians is whether some of these risk factors, if truly present, are iatrogenic, and if known would they change the patient's treatment plan.

Idiopathic condylar resorption (ICR) is a well documented but poorly understood disease.[14] Often in the literature a history of TMD is cited as being a risk factor for ICR. However, ICR is often subclassified under the vague categorization of TMD and is often embedded deep within TMD studies. Even today, a definitive etiology of TMD remains elusive.

An impeding factor regarding the progress of elucidating the etiology, diagnosis and treatment of TMD and condylar resorption in the scientific literature, has been the perpetuation of poor continuity and clarity regarding the specific aspects of TMD in the individual studies. A lack of differential diagnosis, factor definition, representative samples, appropriate groupings of data, definition of terms and a high standard of research method with proper statistical analysis has contributed to controversial data and opinions among researchers and clinicians.[5,6] As a result, it is unclear how inter-related TMD and ICR are. For example, a displaced disk has been blamed for the inability to effectively distribute synovial fluid over the condylar surface. This is said to result in decreased perfusion and tissue necrosis. On the other hand, skeptics hold that the bilateral nature of ICR make this theory unlikely.[101]

As ICR commonly falls under the scope of temporomandibular dysfunction (TMD), it represents a small part of the more comprehensive disease classification. The incidence of ICR is less common than TMD but is sometimes included in epidemiology studies and therefore, reported with a much lower prevalence than that of TMD; up to

25%[27-31] in the general population, and 2-16% in a pre-orthodontic population.[32] Because ICR most commonly occurs at about the same age as those undergoing orthodontic treatment, if a patient develops pain or other symptoms during the course of orthodontic treatment or after a recent adjustment, the patient may blame the orthodontist.

ICR is characterized by condyles which partially resorb causing a loss of condylar height and alteration of the maxillofacial morphology and occlusion. Additionally, it may play a role in the structural incompatability of articular surfaces including a deviation in form, condylar adherences and adhesions.[3] In general ICR has the following features; [63-72]

1. It most often affects females age 15-35 years.
2. May be more frequent in teenage girls during the pubertal growth spurt.
3. Generally results in bilateral symmetric condylar involvement.
4. May result in progressive resorption followed by stabilization without further loss of condylar height
5. Frequently occurs in the natural course of events and not in conjunction with active therapy, although it may be observed during or after restorative, surgical or orthodontic treatment.
6. Generally allows for good TMJ functions without significant limitations in vertical opening or pain, although during active resorption some TMJ discomfort and muscle hyperactivity is expected
7. Persistent joint noise is frequent but the condylar disc remains intact over the resorbing condylar head.
8. Condylar heads change shape by flattening and thinning
9. Condylar height decreases
10. A resultant loss of overall posterior face height is observed
11. Mandibular retropositioning
12. Angle Class II open bite malocclusion

A number of theories have been proposed regarding the origin of ICR. The first is that since young females are more commonly affected, sex hormones may modulate biochemical changes within the joint causing hyperplasia of synovial tissue resulting on bony joint resorption. Estrogen is known to mediate cartilage and bone metabolism in the female TMJ. Estrogen receptors have been found in the TMJ of primates.[72] An increase in receptors may predispose to an exaggerated response to joint loading from parafunctional activity, trauma, orthodontics or orthognathic surgery.[72] Estrogen also controls prolactin which is released from the anterior pituitary and is a hormone responsible for initiating postpartum milk letdown. It can exacerbate cartilage and bone degredation in animal models of arthritides and is a potent stimulator of immune functions by enhancing production of cytokines and lymphocytes.[69] Interestingly, pregnancy influences both estrogen and corticosteroid levels.

A second theory is that pathologic compressive forces or loading of the joint lead to avascular necrosis of the condyle. Compression on retrodiscal soft tissues and ligaments constrict small vessels, limiting circulation to the condyle resulting in loss of condylar height and leading to a change in occlusion and skeletal pattern.[63] Sources of joint compression that have been identified in the literature include: orthognathic surgery, orthodontics, general dentistry, internal derangement, parafunction, unstable occlusion and trauma.[83]

Another similar theory that parallels the former holds that mechanical stress factors provoke molecular, soft tissue and osseous adaptive remodeling responses in the normal temporomandibular joint.[69] Stretch and compression are both forms of mechanical stresses that affect the joint by initiating physical disruption of molecules, impairment of cellular functions, impediment of blood flow or synovial fluid leading to ischemia and finally the release of inflammatory peptides from stretched or compressed nerve terminals. Microinfarcts of vascular channels in marrow spaces resulting from excessive load under function, metabolic disease states, or vascular compromise or stasis from diminished blood supply histologically lead to necrosis and a net loss of articular tissue. This mechanism is well understood in other joints such as the hip.[101] Peltola found a greater variation in condylar shape among orthodontically treated patients compared with controls. These morphological changes presumably represent normal functional remodeling stimulated by changes in mechanical stresses imposed on the joint after occlusal adjustments of orthodontic therapy.[74] On the other hand, Dibbets and van der Wheele previously observed condylar findings emerged and vanished after orthodontic treatment, and no association between orthodontic treatment and condylar findings was found. They concluded that condylar findings can come and go and are difficult to predict.[81] Likewise, Mongini[102] stated that reshaping affects condyles that were previously flattened as a result of occlusal alteration with the new shape tending to be rounded.

A fourth theory holds that chronically dislocated, non-reducing disc or malocclusion can be causative leading to ICR.[63] Arnett[83] states that the most common clinical sign associated with total remodeling is multiple clicks. Kirk[101] states that a displaced disk may result in an inability to effectively distribute synovial fluid over the condylar surface. This is said to result in decreased perfusion and nourishment of cells leading to transient cell anoxia in the fibrocartilage matrix and cortical osteocytes. Necrosis of the fibrocartilage covering and the cortical layer then results in eventual tissue destruction and structural failure of the joint. Although skeptics of this theory hold that the common bilateral symmetric involvement of ICR makes this theory unlikely.

Other factors in condylar resorption may involve corticosteroids. Furstman[109] reported narrowing of condylar cartilage, osteosclerotic trabeculae, and inhibition of normal calcification when rats were subjected to exogenous hydrocortisone. Pellicci[110] reported three cases of osteonecrosis with the effects of increased levels of endogenous corticosteroids associated with pregnancy. Excessive pyschological stress, cardiovascular disease and blood dyscrasias also may be factors.[69] Condylar anatomy characterized by decreased cortication, straight alignment between the condyle neck and head, decreased condylar size, thin and finger-like in shape and fuzzy in appearance on a tomograph have been stated to be less stable and less resistant to condylar resorption if displaced during treatment.[69,70,83] The foregoing theories remain unproven and therefore the treatment that a person receives for ICR will depend on the clinicians belief about the disorders etiology.

As the condyle resorbs through a degenerative process it takes on a mushroom shape radiographically and leads to a vertical shortening of the ramus.[33] This shape is easily recognizable due to its distinctive appearance and as previous research has established can be diagnosed from a panoramic radiograph. [35,63,74,77] This is convenient for orthodontists as panoramic radiographs are taken routinely as part of the treatment planning record. Surface erosions and osteophytes are radiographic hallmarks for degenerative joint disease of the TMJ. Marginal erosions represent the early stages of degenerative change and are described radiographically as a local area in the condyle with decreased density of the cortical joint surface and adjacent subcortical bone.[62,78] Osteophytes represent the later stage of degenerative change as the body is adapting to repair the joint and are observed as cartilage and bone formation appearing on the radiograph as a marginal bony outgrowth.[62,78] Osteophytes are created to stabilize and broaden the surface of the joint in an attempt to better withstand loading forces.[62] Other radiographic findings include flattening of the articular surface, subcortical sclerosis, concavity, deviation in the shape of the condyle and irregular condylar boarder.[74-76]

Because of the devastating sequela associated with resorption of the temporomandibular joint and uncertainty involved in the etiology of CR and the potentiating effects of orthodontic therapy through changing occlusion, jaw or joint position, it is imperative that orthodontists are able to recognize and take into account risk factors associated with the abnormality. It is crucial that we seek to identify these risk factors.

Risk factors published in the literature associated with TMD, and by convention may also be associated with ICR include:[63]

1. Facial asymmetry[37,38]
2. non-coincident dental midlines[37,38]
3. decreased range of motion and maximal mouth opening <35mm[18,39]
4. reduced protrusive and laterotrusive excursions[39]
5. joint sounds or disc displacement (DD) [18,39,40,106]
6. history of trauma[18]
7. Angle Class II molar relationship[41-43]
8. large maximal intercuspation-retruded contact position slide[44]
9. horizontal overlap of the incisors greater than or equal to 4mm[45], or greater than 6-7mm[46]
10. openbite[43]
11. abnormal wear pattern on teeth[42]
12. bruxism and wear facets[42]
13. balancing contacts[41]
14. missing more than 5 posterior teeth[42,46-49]
15. tilted teeth[42,50]
16. soreness in muscles of mastication[42]
17. other joint problems[18,5]
18. family history of jaw pain[18]
19. pain when chewing, eating or speaking[40]
20. female gender[28,51,52]
21. orthognathic surgery[61]

It is noteworthy to mention that the functional occlusal relationship itself is not considered or demonstrated in the literature to be a risk factor for TMD; i.e. no cause-and-effect relationship was established.[45,53-55]

Various researchers have examined the skeletal morphology of TMD, DJD, and DD patients radiographically and established the following cephalometric risk factors[62]:

1. Overjet greater than or equal to 4 to 7mm. [45,46]

2. mandibular plane greater than 30° [37,56]
3. palatal plane greater than 31° [37,56]
4. gonial angle greater than 130° [37,56]
5. condyles that are tipped back[32,37,56]
6. antigonial notching[32,37]
7. increased angle between the posterior border of the mandibular ramus and Sella-Nasion.[56] (angle measured anterior to posterior boarder or the ramus)
8. decrease in Rickett's facial axis[56]
9. reduced posterior facial height[56]
10. reduced ramus height[56]
11. reduced posterior cranial base vertical height[56]
12. increased occlusal plane to Frankfort Horizontal[32,37]
13. increased overjet[37,45,46,57]
14. maxillary[58] and mandibular[37] retrusion
15. increased ANB angle[37]
16. Class II skeletal pattern[34,43,59]

This study is a sequel of an initial study undertaken at The University of Western Ontario by DH Bharwani in 2009. Results from that previous study provided an accepted condylar scoring method using panoramic radiographs that has been utilized in the literature by other authors.[35,53,79,80,81] From that study, a group of subjects with moderate to severe condylar resorption (CR) was identified and observations were made based on recorded orthodontic treatment modalities and skeletal characteristics identified on cephalometric radiographs.

The purpose of this study is three fold:

1. To compare morphological differences between a) a control group with no condylar resorption b) a mild idiopathic condylar resorption group and c) a moderate-severe condylar resorption group.

2. To compare cephalometric measurements and orthodontic treatment modalities among the three groups.

3. To determine the relationship between TMJ condylar changes over time and factors associated with orthodontic treatment and various dento-skeletal characteristics so as to identify risk factors associated with condylar changes.

The null hypotheses for this study are as follows:

1. There is no difference in vertical skeletal morphology as characterized by the four primary measurements: MPA, AFH/PFH ratio, gonial angle, Rickett's facial axis among the condylar resorption groups.
2. There is no difference in anterior-posterior skeletal morphology as characterized by the four primary measurements: ANB, SNB, facial convexity, Pg-Na perpendicular demonstrating Mn retrognathia among the condylar resorption groups.

3. There is no difference in dental characteristics as characterized by the three primary measurements: OJ, U1-PP, L1-MP among the condylar resorption groups.

4. There is no difference related to a history of trauma, splint therapy, TMJ or muscular pain during treatment, or differing modalities of orthodontic treatment such as CL II, III elastics or orthognathic surgery among the condylar resorption groups.

Materials and Methods

In the previous study,[63] subjects were selected from the archived charts of 2018 patients treated at the University of Western Ontario, Department of Orthodontics, in London, Ontario, Canada, between 1983 and 2007. Panoramic radiographs were used to assess the degree of resorption present in each condyle at three time points (T1 = prior to orthodontic treatment, T2 = immediately after orthodontic treatment, T3 = two years post-treatment) for each patient. These scores for were based on a diagnostic method established by Helenius et al. [79] to evaluate the TMJ condyles of patients with condylar erosion. Condylar scoring of all panoramic radiographs for all subjects was done by D.H. Bharwani.

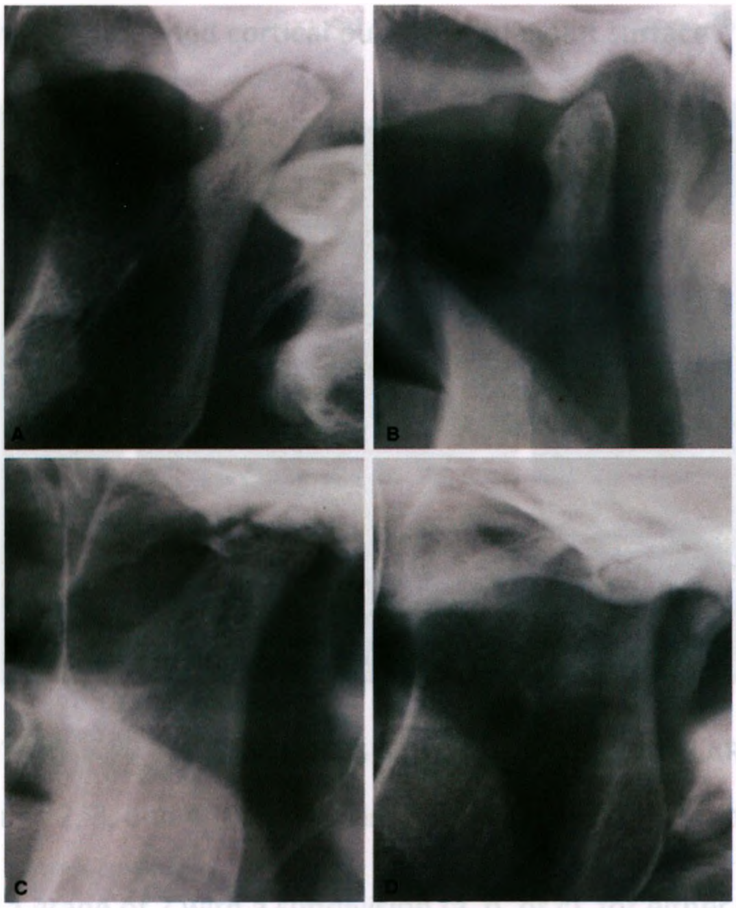
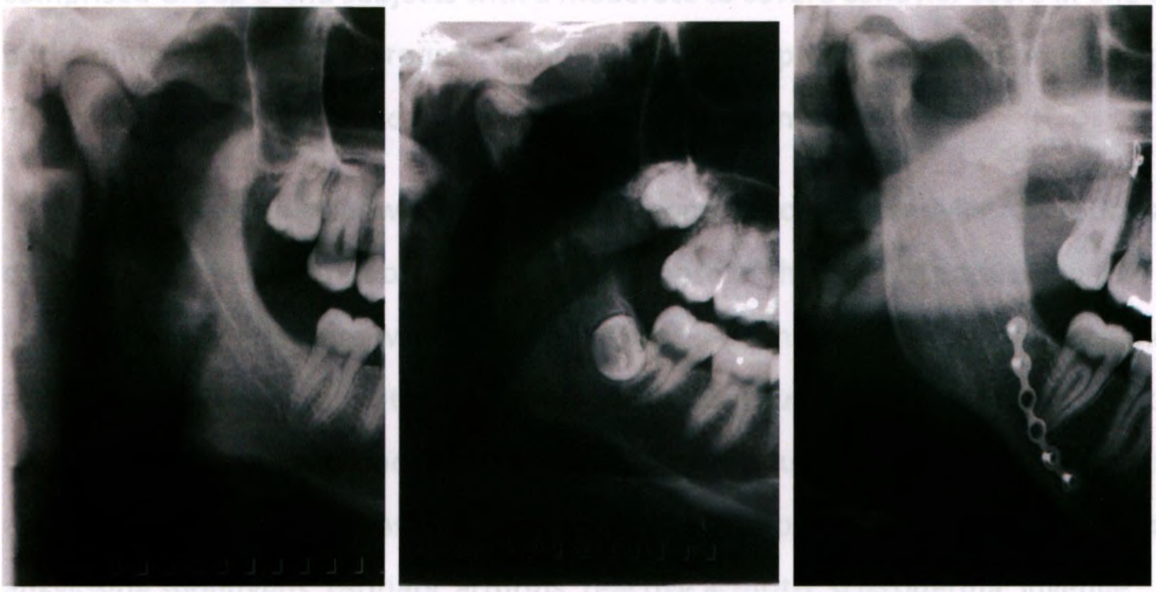


Figure 1. TMJ condylar assessment score guide

Figure 1 Legend: Condylar resorption scores were designated as follows: Grade 0 – no erosion of the TMJ condyle, Grade 1 – very slight erosion of the TMJ condyle (A), Grade 2 – erosion of the top of the TMJ condyle (B), Grade 3 – half of the condyle eroded (C), Grade 4 – complete erosion of TMJ condyle (D).

Three subdivisions (2a, 2b, and 2c) were added to the Helinus et al scoring system by D.H. Bharwani and A.H. Mamandras to allow for those condylar surfaces with irregularities.[76,78,82] These included condyles with an initial assessment score of 2 plus one of the following:

a) osteophyte – a marginal bony outgrowth[76,78,82]
b) sclerosis – a local area with increased density of the cortical bony joint surface extending into the subcortical bone[76,78,82]
c) irregular border or concavity – a hollowed out area on the bony contour with a well-defined cortical outline of the joint surface[76,78,82]



OSTEOPHYTE (a) SCLEROSIS (b) IRREGULAR BOARDER

Figures 2, 3, and 4. Condylar assessment score subdivisions

A subject assigned a grade of 2 with a subdivision (a, b, or c), for either or both condyles was assigned to the moderate-severe group. When a subject had a score that was borderline between 2 and 3, a second examiner was consulted and a consensus was reached.

Based on the presence of condylar resorption at T3, subjects were then divided into three subject groups; A group with normal condylar morphology in both condyles at T3, a group with mild condylar resorption in one or both condyles at T3, and a group with moderate to severe condylar morphology in one or more condyles at T3. Subjects were assigned based on the condyle with the most severe CR score. Sixty-one patients were first identified among the 2018 archived subjects by D.H Bharwani to have moderate to severe CR.

In the present study, an equal number of subjects were then selected randomly from the remaining two pools of 1957 archived subjects with normal and mild condylar scores respectively. Subjects with normal condylar morphology in both condyles comprised Group A, subjects with mild condylar resorption in one or both condyles comprised Group B and subjects with a moderate to severe condylar score in one or both condyles comprised Group C. Group C subjects represent the experimental group. The other two groups, A and B, represent the controls in this study.

Patients with a known medical history contributory to condylar resorption and considered at a higher risk of resorption than those of the general population as identified in the literature were excluded. These persons would likely influence the results of this study attempting to identify resorption due specifically to orthodontic treatment or idiopathic condylar resportion. These included chronic corticosteroids, autoimmune disease such as systemic lupus erythematosis (SLE), Sjogrens syndrome, ankylosing spondylitis, psoriatic arthritis, reactive arthritis, scleroderma, juvenile rheumatoid arthritis, hyperparathyroidism.[64] In order to be included in this study, subjects must have had complete radiographic records including panoramic radiographs taken prior to the initiation of treatment (T1), at the time of removal of all appliances marking the termination of active treatment (T2), and two years post-treatment during the retention period (T3). In addition, cephalometric radiographs must have been taken at T1.

The lateral cephalometric radiographs were traced for each subject in Groups A, B and C. Specific cephalometric measurements were included for the purpose of evaluating overall soft tissue, skeletal, and dental pattern of each subject.

Charts of all subjects included in the three study groups were reviewed by one author (ZTW) and the following information regarding treatment-related and patient-related factors were recorded:

1. Gender
2. Racial background
3. Age at initiation of treatment
4. Age at termination of treatment or deband (where available)
5. Age at 2 years post-treatment (where available)
6. Treatment duration
7. Appliances used during treatment (headgear, functional appliance, Class II or III elastics, palatal expansion appliance such as a hyrax or quad helix, and anterior or posterior bite plate)
8. Treatment modalities (orthognathic surgery and extraction of permanent premolar teeth)
9. Other data noted was impaction of canines, orofacial trauma, pain prior to or during treatment, occlusal splint treatment prior to or during treatment, and congenitally missing teeth

All pre-treatment lateral cephalometric radiographs were traced by one author (ZTW) using Dolphin Imaging 10.0. for the purpose of comparison between each of the three groups

Cephalometric variables to be utilized in the analysis of subjects were divided into five groups and included the following: (for specific measurements see Table 13, page 53).

1. Cranial base measurements
2. Soft tissue profile measurements
3. Vertical measurements
4. Skeletal measurements
5. Dental measurements

All statistical analyses were performed using the JMP 8 statistical program. Descriptive statistics; i.e. measures of central tendency and spread and associations (correlations) were used to describe the study findings. The study hypotheses were tested using one-way analysis of variance (ANOVA). Where a statistically significant difference was observed among the three groups, the Tukey-Kramer test was used to determine statistical significance for pair-wise comparisons. Since multiple t-tests can increase the risk of a false positive finding, the Bonferroni method (critical p-value/number of tests) is employed to adjust the critical p-value.

Thirty-three cephalometric radiographs, with all 44 points, were re-traced approximately six months after the initial tracings by the same author to calculate the reproducibility of the measurements (intra-class correlation coefficient or R).

Results

There were 2018 patients in the archives of the Graduate Orthodontic Clinic, University of Western Ontario. Sixty-one of those patients (3.02%) had moderate to severe condylar resorption at retention (T3). However, nine of those patients did not have complete radiographic records and were excluded leaving 52 subjects in Group C. Groups A and B each had 61 subjects, all with complete radiographic records. No subjects were excluded from the study due to medical history findings that would be contributory to CR (Table 1).

Table 1. Treatment groups

2018 total UWO archived patients			
Group	A	B	C
Sample selected in Part I	0	0	61

1957 remaining UWO archived patients			
Group	A	B	C
Sample selected in Part II	61	61	0
Subjects dropped for incomplete records	0	0	9
Final n per group	61	61	52

A measurement error analysis was performed for all the cephalometric measurements resulting in an average intra-operator coefficient correlation (R) = 0.966, with a range of 0.80-0.99. This magnitude of error was deemed acceptable. For a specific description of the error study and individual measurement error calculations see Appendix III.

The characteristics of the three study groups are presented in Table 2. The study groups were quite evenly matched for age and gender. Race was predominantly Caucasian in all study groups with only five subjects being East Indian or Asian. Treatment duration was somewhat longer in Group C compared with the other two groups. A statistically significant difference in treatment duration was noted between Group C and Group A; however, no statistically significant difference in treatment duration was noted between Group B and either Group A or Group C.

Table 2. Study Group Characteristics

Subject Demographic	Group A: Mean (SD) or (% of group)	Group B: Mean (SD) or (% of group)	Group C: Mean (SD) (% of group)	p value
Total number	61	61	52	NS
Males	26 (43%)	22 (36%)	20 (38%)	NS
Females	35 (57%)	39 (64%)	32 (62%)	NS
Caucasian race	59 (97%)	59 (97%)	51 (98%)	NS
Age at T1	13.5 (3.7)	14.4 (4.8)	13.8 (3.7)	NS
Age at T2	16.1 (3.6)	17.3 (4.7)	17.3 (3.4)	NS
Treatment duration	2.6 yrs (10.7mo)[a]	3.0 yrs (13.5 mo)[ab]	3.4 yrs (17.4 mo)[b]	p= 0.002

[a,b] Statistical significance is reported between individual study group means in the same row using an alternate letter in superscript.

[ab] Study group means with the same letters represent no statistically significant difference.

Table 3 presents the treatment variables for the three study groups. Class III elastics, a history of orthognathic surgery, splint therapy and a history of orofacial trauma were found to be distributed unequally among the study groups. A smaller proportion of Group C subjects had Class III elastics involved in their treatment or a history of orofacial trauma but a much higher proportion of Group C subjects experienced splint therapy and orthognathic surgery compared to Groups A and B.

Table 3. Treatment variables

Treatment variable	Group A (n=61) (% of group)	Group B(n=61) (% of group)	Group C (n=52) (% of group)	p value
Headgear	27 (44%)	27 (44%)	17 (40%)	NS
Functional appliance	4 (7%)	1 (2%)	5 (10%)	NS
Class II elastics	35 (57%)	40 (66%)	32 (62%)	NS
Class III elastics	10 (16%)	17 (28%)	5 (10%)	p= 0.0431
Orthognathic surgery	3 (5%)	5 (8%)	14 (27%)	p= ≤0.001
Premolar extractions	30 (49%)	26 (43%)	24 (46%)	NS
Splint therapy	1 (2%)	2 (3%)	6 (12%)	p= 0.043
TMJ or muscular pain during treatment	2 (3%)	6 (10%)	3 (6%)	NS
Congenitally missing teeth	1 (2%)	0 (0%)	3 (6%)	NS
Bite plate	5 (8%)	7 (11%)	4 (8%)	NS
Palatal expansion (RPE or quad helix)	6 (10%)	10(16%)	8 (15%)	NS
Impacted canines	0 (0%)	4 (7%)	2 (4%)	NS
History of orofacial trauma	8 (13%)	6 (10%)	0 (0%)	p= 0.0312

Tables 4-8 present the cephalometric characteristics of the subjects in the three study groups. Nasolabial Angle (NLA) was more obtuse in Group C than in the other two groups by four degrees.

SNA, SNB, Mx/Mn difference and articular angle all show very highly statistically significant differences between Groups C and A as well as Group C and B (p= <0.0001). SNA was smaller in Group C by about three degrees compared to the other groups. Wits was increased in Group C compared to the other two groups with a mean value of 2.6 (p=0.0225). Mx/Mn difference showed a decreased difference with a mean of 27.6 mm in Group C compared with a mean of 32.4mm in Group B and a mean of 31.9mm in Group A. The mean articular angle in Group C subjects was at least three degrees more acute than the mean articular angle found in subjects in the other two groups.

IMPA showed that lower incisors are more upright in Group C (p= 0.0003) compared to the other two groups by approximately five degrees. Overjet was increased in Group C over Group B by approximately 2mm (p= 0.0099), but there was no significant difference between Group C and Group A.

SN-PP, SN-OP, SN-MP, Ar-Go-Me, Y-Axis (SGn-SN), P-AFH, measurements all show a very highly statistically significant difference between Groups C and A as well as Groups C and B (p= <0.0001). SN-PP as well as SN-OP and SN-MP are all steeper in Group C when compared to the other groups. Gonial angle was more obtuse in Group C with a mean of 133.5 degrees. This is four degrees steeper than Group A and six degrees steeper than Group B. Y-Axis using SN is significantly larger by about three degrees but it was not significant when using FH by Down's as all three groups are essentially the same.

Rickett's Facial Axis was significantly more negative with a mean of -2.3 degrees in Group C. This is larger than Group A or B which have a mean measurement of 0.3 and 0.4 degrees respectively. UFH, LFH measurements also all show a statistically significant difference between Groups C and A as well as Groups C and B with a mean difference of approximately 1-2% between the groups.

In Group C, FMA shows a mean difference approximately 3 degrees between Group A (p= 0.0046) and no significant difference between Group B.

P-AFH% shows a highly significant difference between Groups C and the other two groups (p= <0.0001). The mean difference between the Group C and B, and Group C and A is 3.5% and 2.1% respectively.

Cephalometric characteristics at T1

Table 4. Soft tissue profile measurements

Measurement of *Soft Tissue Profile*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
Nasolabial Angle (°)	109.6[a] (9.2)	110.0[a] (8.5)	114.7[b] (9.1)	p= 0.0049
Facial Angle (FH-NPo) (°)	86.8[a](2.8)	86.7[a] (3.2)	85.8[a] (3.3)	NS
Facial Convexity (A-NPo) (mm)	3.1[a] (3.1)	2.6[a] (2.5)	3.2[a] (2.7)	NS
Lower lip – E Plane (mm)	0.12[a] (3.3)	-0.06[a] (3.0)	-0.68[a] (3.3)	NS

Table 5. Cranial base measurements

Measurement *Cranial Base*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
NSBa (°)	127.9[a] (5.5)	127.3[a] (5.6)	130.5[b] (4.3)	p= 0.0029 (C&B) p= 0.0198 (C&A)

Table 6. Anterior-posterior skeletal measurements

Measurement *Skeletal*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
SNA (°)	83.5^{a} (4.4)	83.3^{a} (4.1)	80.1^{b} (3.3)	p=<0.0001
SNB (°)	79.1^{a} (4.0)	79.2^{a} (4.0)	75.7^{b} (3.5)	p=<0.0001
ANB (°)	4.4^{a} (2.9)	3.8^{a} (2.3)	4.4^{a} (2.2)	NS
A-Na perpendicular (mm)	0.2^{a} (3.8)	-0.3^{a} (3.5)	-1.0^{a} (3.4)	NS
Pg-Na perpendicular (mm)	-5.7^{a} (5.4)	-5.5^{a} (6.3)	-7.9^{a} (6.3)	NS
Wits (mm)	$1.3^{a,b}$ (3.0)	0.9^{a} (3.4)	2.6^{b} (3.9)	p=0.0225
Maxillary Length (Co-A) (mm)	85.7^{a} (4.8)	85.7^{a} (4.9)	84.5^{a} (3.9)	NS
Mandibular Length (Co-A) (mm)	118.1^{a} (7.6)	118.7^{a} (7.4)	116.4^{a} (7.7)	NS
Mx/Md Difference (mm)	31.9^{a} (5.8)	32.4^{a} (5.9)	27.6^{b} (5.7)	p=<0.0001
Articular Angle (S-Ar-Go) (°)	$143.4^{a,b}$ (9.0)	145.7^{a} (6.6)	140.3^{b} (7.7)	p= 0.001

Table 7. Dental measurements

Measurement *Dental*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
U1-SN (°)	105.3^{a} (8.5)	105.3^{a} (9.1)	103.9^{a} (8.6)	NS
U1-NA (°)	22.0^{a} (8.6)	22.3^{a} (8.8)	23.7^{a} (8.2)	NS
U1-NA (mm)	4.5^{a} (3.3)	4.8^{a} (3.1)	5.5^{a} (3.0)	NS
U1-PP (°)	108.9^{a} (7.6)	109.6^{a} (8.3)	111.4 (7.8)	NS

U1-L1 (°)	128.0[a] (12.7)	128.8[a] (10.8)	130.1[a] (11.4)	NS
L1-Apo (mm)	1.6[a] (3.0)	1.7[a] (2.5)	1.2[a] (2.7)	NS
IMPA (°)	92.2[a] (8.0)	92.7[a] (5.9)	87.5[b] (6.8)	p= 0.0003
Overbite (mm)	2.8[a] (2.9)	2.8[a] (3.0)	3.0[a] (2.4)	NS
Overjet (mm)	5.8[a,b] (2.7)	5.4[a] (2.4)	7.1[b] (3.6)	p=0.0099

Table 8. Vertical measurement

Measurement *Vertical*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value

Palatal Plane

SN-PP (°)	3.6[a] (3.2)	4.4[a](3.8)	7.3[b] (3.2)	p= <0.0001
PP-MP (°)	31.0[a] (6.2)	28.6[a] (5.6)	31.1[a] (5.5)	NS
PP-OP (°)	11.2[a] (3.9)	9.9[a] (3.3)	9.6[a] (4.1)	NS

Occlusal Plane

SN-OP (°)	14.7[a] (4.2)	14.4[a] (4.2)	16.9[b] (4.8)	p= <0.0001
FH-OP (°)	7.8[a] (3.8)	7.6[a] (3.9)	8.0[a] (4.7)	NS

Mandibular Plane

SN-MP (°)	34.6[a] (6.2)	33.1[a] (5.8)	38.4[b] (5.4)	p= <0.0001
FMA (°)	27.6[a,b] (5.5)	26.4[a] (5.0)	29.5[b] (4.8)	p= 0.0046

Gonial Angle

Ar-Go-Me (°)	129.5[a] (8.5)	127.1[a] (6.5)	133.5[b] (7.1)	p= <0.0001

Ar-Go-Gn (°)	128.0^{a} (6.5)	126.1^{a} (5.4)	127.6^{a} (4.8)	NS

Others

Ramus Height (Ar-Go) (mm)	42.6^{a} (4.8)	44.0^{a,b} (5.0)	45.3^{b} (6.1)	p= 0.0046
Rickett's Facial Axis (°) Ba-Na^Pt-Gn	0.4^{a} (4.5)	0.3^{a} (3.7)	-2.3^{b} (4.1)	p= 0.0001
Y-axis (Down's) SGn-FH (°)	59.5^{a} (3.4)	59.5^{a} (3.4)	60.0^{a} (3.2)	NS
Y-axis SGn-SN (°)	66.5^{a} (4.2)	66.2^{a} (3.9)	69.5^{b} (3.8)	p= <0.0001
AFH (NaMe) (mm)	115.4^{a} (8.4)	115.4^{a} (7.3)	118.8^{a} (7.8)	NS
PFH (SGo) (mm)	73.8^{a} (5.4)	75.5^{a} (6.5)	73.8^{a} (6.4)	NS
P-AFH (S-Go/N-Me) (%)	64.1^{a} (3.8)	65.5^{a} (4.8)	62.0^{b} (4.3)	p= <0.0001
UFH (N-ANS) (%)	42.3^{a} (2.6)	42.7^{a} (2.3)	43.8^{b} (2.2)	p= 0.0396
LFH (ANS-Me) (%)	57.7^{a} (2.6)	57.3^{a} (2.3)	56.2^{b} (2.2)	p= 0.0396

Since 22 (12.64%) of the subjects had a history of orthognathic surgery and Group C subjects had a much higher proportion of subjects with a history of orthognathic surgery compared with subjects in the other two groups, further investigation of those subjects was undertaken. Analysis was performed using the same cephalometric measurements and other treatment modalities associated with orthognathic surgery in attempt to identify a statistically significant difference between two new groups; a surgical group (n=22) and a non-surgical (n=152) group. T-tests were utilized to identify any statistically significant differences in mean values between the surgery and non-surgery groups. Table 9 contrasts the skeletal characteristics among subjects who did and did not undergo orthognathic surgery. Among those who had orthognathic surgery, increased vertical craniofacial measurements, increased overjet, proclined upper incisors, upright lower incisors, increased Wits, decreased SNA and SNB and a more obtuse nasolabial angle (NLA) were found to exist compared to those subjects who did not undergo orthognathic surgery. Although only NLA was statistically significant, only MP-SN, Facial Axis, overjet, SN-PP, L1-MP, SNA and SNB were considered to be clinically meaningful.

Table 9. Cephalometric measurements by orthognathic surgery at T1

Vertical measurements

Measurement	Orthognathic Surgery Yes (n=22) Mean (SD)	Orthognathic Surgery No (n= 152) Mean (SD)	p value
MP-SN(°)	38.34 (5.40)	34.77 (6.18)	p= 0.0110 (NS)
MP-FH(°)	29.82 (4.48)	27.47 (5.30)	p=0.0495 (NS)
Facial axis(°)	-2.49 (5.22)	-0.16 (4.04)	p=0.0163(NS)
P-AFH%	62.36 (3.50)	64.19 (4.58)	p= 0.0745 (NS)
SN-PP(°)	6.87 (4.32)	4.75 (3.60)	p= 0.0129(NS)
SN-OP(°)	16.49 (5.81)	15.11 (4.27)	p= 0.2942(NS)
Gonial angle(°)	132.97(7.97)	129.45 (7.71)	p= 0.0475(NS)

Anterior-posterior measurements

Overjet (mm)	7.38 (4.50)	5.85 (2.66)	p= 0.0110 (NS)
U1-PP(°)	110.2 (7.7)	109.9 (8.0)	p= 0.8265 (NS)
L1-MP(°)	87.83 (7.02)	91.45 (7.22)	p= 0.0286 (NS)
SNA(°)	80.41 (4.30)	82.72 (4.20)	p= 0.0171 (NS)
SNB(°)	75.96 (5.03)	78.44 (3.93)	p= 0.0083 (NS)
ANB(°)	4.15 (2.35)	4.46 (3.49)	p= 0.5758 (NS)
Wits(mm)	2.89 (4.16)	1.36 (3.34)	p=0.0552 (NS)

Cranial Base

SN-Ba(°)	129.2 (4.7)	128.8(5.4)	p= 0.4417 (NS)

Soft Tissue

NLA Col-Sn-UL(°)	115.80 (8.84)	110.60 (9.07)	p= <0.0001

Table 10. Treatment variables by orthognathic surgery

Treatment variable	Orthognathic Surgery Yes, n=22 (% of group)	Orthognathic Surgery No, n=152 (% of group)	p value
History of splint therapy	6/22 (27.27%)	3/152 (1.97%)	p=0.0001
History of orofacial trauma	2/22 (9.09%)	12/152 (7.89%)	NS

Splint therapy was utilized to a much greater extent in subjects with a history of orthognathic surgery compared to those without surgery but there was a more or less equal history of orofacial trauma between the surgery and non-surgery subjects (Table 10).

Condylar change over time

The primary focus of this study was to evaluate the relationship of condylar resorption at T3 among the groups using a variety of pre-treatment cephalometric landmarks and orthodontic treatment-related factors. However, as orthognathic surgery was the most highly significant difference among the original three condylar resorption groups, the association between a change in condylar resorption over time and a history of orthognathic surgery was subsequently explored. Therefore, any change in condylar resorption that occurred over the course of orthodontic treatment and during the retention period was noted. Twenty-one categories were created to represent the qualitative change in condylar resorption occurring from T1 to T3 (Table 11). Only the condyles initially used to classify subjects into the condylar resorption groups at T3 were compared over time.

Table 11. Condylar change over time by orthognathic surgery

Condylar Change Category (T1-T3)	Orthognathic Surgery Yes (% of total)	Orthognathic Surgery No (% of total)
A (0-0)	3/22 (13.64%)	58/152 (38.16%)
B (0-1)	1/22 (4.55%)	18/152 (11.84%)
C (0-2)	1/22 (4.55%)	19/152 (12.50%)
D (0-2.5)	0/22 (0.00%)	2/152 (1.32%)
E (0-3)	**8/22 (36.36%)**	18/152 (11.84%)
F (0-4)	1/22 (4.55%)	0/152 (0.00%)
G (1-1)	0/22 (0.00%)	5/152 (3.29%)
H (1-2)	2/22 (9.09%)	12/152 (7.89%)
I (1-2.5)	0/22 (0.00%)	1/152 (0.66%)
J (1-3)	1/22 (4.55%)	5/152 (3.29%)
L (2-2)	1/22 (4.55%)	3/152 (1.97%)
N (2-3)	3/22 (13.64%)	7/152 (4.61%)
O (2-4)	1/22 (4.55%)	0/152 (0.00%)
S (3-3)	0/22 (0.00%)	3/152 (1.97%)
T (3-4)	0/22 (0.00%)	1/152 (0.66%)
U (4-4)	0/22 (0.00%)	0/152 (0.00%)

The most common category among subjects with no history of orthognathic surgery was category A. Thirty-eight per cent of subjects with no history of orthognathic surgery showed no condylar resorption and no change over time from T1-T3. Category E was the largest category among those with a history of orthognathic surgery. Thirty-six per cent of subjects who had previously undergone orthognathic surgery started with no condylar resorption and progressed to moderate to severe condylar resorption from T1-T3 (Table 11).

Table 12. Condylar change over time by orthognathic surgery

Condylar Change (CR categories)		Surgery	Non-Surgery
No CR Change	0-0 (A)	3/22 (13.64%)	58/152 (38.16%)
	1-1(G)	0/22 (0.00%)	5/152 (3.29%)
	2-2 (L)	1/22 (4.55%)	3/152 (1.97%)
	3-3 (S)	0/22 (0.00%)	3/152 (1.97%)
	4-4 (U)	0/22 (0.00%)	0/22 (0.00%)
	Total	4/22 (18.18%)	69/152 (45.39%)
Mild CR Change	0-1 (B)	1/22 (4.55%)	18/152 (11.84%)
	0-2 (C)	1/22 (4.55%)	19/152 (12.50%)
	1-2 (H)	2/22 (9.09%)	12/152 (7.89%)
	1-2.5 (I)	0/22 (0.00%)	1/152 (0.66%)
	2-2.5(M)	0/22 (0.00%)	0/22 (0.00%)
	Total	4/22 (18.18%)	50/152 (32.89%)
Moderate to severe CR change	0-2.5(D)	0/22 (0.00%)	2/152 (1.32%)
	0-3 (E)	8/22 (36.36%)	18/152 (11.84%)
	0-4 (F)	1/22 (4.55%)	0/152 (0.00%)
	1-3 (J)	1/22 (4.55%)	5/152 (3.29%)
	1-4 (K)	0/22 (0.00%)	0/22 (0.00%)
	2-3 (N)	3/22 (13.64%)	7/152 (4.61%)
	2-4 (O)	1/22 (4.55%)	0/152 (0.00%)
	3-4 (T)	0/22 (0.00%)	1/152 (0.66%)
	Total	14/22 (63.64%)	33/152 (21.71%)

In order to better comprehend the degree of condylar resorption that occurred from T1 to T3, the 21 categories were grouped to reflect those subjects who had no change in condylar resorption, a mild degree of change in condylar resorption or a moderate to severe degree of change in condylar resorption (Table 12). Of 152 subjects who had no history of orthognathic surgery, 69 subjects (45%) also had no condylar change from T1-T3. Of those who had orthognathic surgery, four out of 22 (18%) also showed no condylar change. A moderate to severe change in condylar resorption was exhibited by 14 of 22 subjects (64%) of those who had orthognathic surgery. The same amount of resorption was identified in only 33 out of 152 subjects (22%) of those who had no history of orthognathic surgery.

Discussion

The previous study by DH Bharwani [63] noted that the overall cephalometric profile of subjects with moderate to severe condylar resorption was characterized by mandibular retrognathia superimposed upon a dolicofacial pattern with a steep mandibular plane angle, large gonial angle with upright lower incisors and increased overjet. This was in agreement with Neebe[37] who noted alterations in facial morphology of adolescent females associated with articular disc displacement of the TMJ. The present study also resulted in similar findings with the exception that there was less indication of mandibular retrognathia relative to the maxilla in comparison to the other studies,[37,63] but rather a counter clock-wise or downward and backward growth pattern with a retrognathic maxilla and mandible.

It is also worth mentioning that because greater than twenty t-tests were performed among the original groups A, B and C as well as among the surgery and non-surgery groups due to the extensive list of variables, the p-value could be affected and should be less than 0.003 to be significant. As this is the case with the present study, there are many measurements that show a statistical significance with $p \leq 0.05$ however, there are much fewer measurements that show a value of $p \leq 0.003$ and if they do are they really clinically significant?

Statistically significant differences in pre-treatment facial angle (FH-NPo) indicating mandibular retrognathia were not identified as found by other studies,[2] as the differences between the means were very small. Surprisingly the ANB angle was not significantly different nor was Pg-Na perpendicular distance which could also indicate mandibular retrognathia. Despite not being statistically significant, a clear trend was seen between the groups indicating a decrease in PG-Na perpendicular which may be clinically significant in Group C due to the differences between the means, -7.9mm for Group C compared to -5.7mm and -5.5mm for Groups A and B respectively (Table 6). However it is worth noting here that the standard deviations are larger than the differences between the means.

A decrease in pretreatment facial axis was statistically significant with moderate to severe condylar resorption and an increase in Y-axis (SGn-SN) was also observed in Group C, both of which indicate a counter-clockwise growth pattern where the mandible relocates downward and backward with growth (Table 8). It is possible that craniofacial form may have been influenced by a number of subjects who presented at the initial time point with actively occurring condylar resorption or resorption that had already occurred and had arrested. It was beyond the scope of this study however to know whether in these cases growth is simply manifesting in a vertical direction or whether there is some contribution to craniofacial form by CR creating a downward and backward mandibular rotation at T1.

Horizontal measurements (Table 6) found to be statistically significant with CR included Mx/Mn differential, OJ, SNA and SNB. Mx/Mn differential ironically was significantly smaller in Group C when compared with Groups A and B. This was unexpected but also suggests a lack of evidence supporting mandibular retrognathia. Another interesting finding was that ANB was not significant. SNA and SNB were both decreased in the moderate to severe CR group when compared to the mild or control group. This may be in disagreement to some studies[34,37,43,49] suggesting that there may not have been a significant Class II skeletal pattern as identified by ANB angle. However this is in agreement with Gidarakou et al [2] comparing those with bilateral degenerative joint disease and asymptomatic normal volunteers, a study which indicated that both upper and lower denture bases are retruded in DJD subjects. ANB may be misleading if used alone to indicate horizontal skeletal pattern. Wits noted that the vertical and anterior-posterior position of nasion can affect ANB, as well rotation of the dental bases. It is possible that the vertical position of nasion was more superiorly positioned with respect to sella in the severe CR group as indicated by a statistical significance between Group C and the other groups for MP-SN but not for MP-FH. This is also shown in the difference between the two Y-Axis measurements. Down's Y-axis (SGn-FH) showed no difference among the groups whereas Y-axis (SGn-SN) was significantly increased in Group C (Table 8). A steeper anterior cranial base plane (SN) again fits with the overall dolicofacial pattern as identified by the other vertical cephalometric measurements and as identified in the literature as more common among those with CR. Subtelny[105] reported varying degrees of involvement of the TMJ whether dysmorphic or dysfunctional when associated with a vertical growth pattern.

Pre-treatment cephalometric skeletal measurements indicating a vertical growth pattern (see Table 8) significantly associated with severe CR included; increased MP-SN, increased MP-FH (although not significant to $p \leq 0.003$), decreased Facial Axis, increased SN-PP, increased SN-OP, increased Y-axis (SGn-FH), increased Gonial angle and decreased P-AFH ratio (though not likely clinically significant due to small differences between the means). Similarly, Gidarakou et al [2] found increased MPA, Y-axis (S-Gn to FH), gonial angle and decreased ramus height in those with CR. However, it is not clear in his study whether these vertical tendencies existed prior to resorption of the condyle. Dibbets et al[34] reported similar skeletal deviations in growing children with temporomandibular dysfunction. These children had reduced ramal height, steeper mandibular plane, increased gonial angle and increased lower face height.

Dental measurements found to be statistically significant among those with moderate to severe CR included decreased L1-MP. Overjet was statistically significant as lower incisors were retroclined with respect to mandibular plane (Table 7 page 21). This is in agreement with Gidarakou et al[2] who found overjet to be significantly increased among asymptomatic and symptomatic patients with bilateral degenerative joint disease. Kahn et al[43] also found that overjet equal to or greater than 4mm was greater in symptomatic patients with intra-articular temporomandibular joint disorders.

No soft tissue measurements found to be significant with CR among Groups A, B and C, yet those with a history of orthognathic surgery did demonstrate a significantly more obtuse NLA which may be indicative of vertical facial form ($p \leq 0.0001$) and a possible rationale for orthognathic surgery. NLA however was by far the most error-prone measurement in the cephalometric analysis (See Appendix III for a list of individual error measurements).

A history of splint therapy was found to be statistically significant among those who had orthognathic surgery ($p=0.0001$) but not between the Group A, B and C ($p= 0.0430$). However, the actual number of subjects who had splint therapy was quite small. Among the surgical groups, three subjects out of 152 (1.7%) had splint therapy with no history of orthognathic surgery. Six subjects out of 22 (27%) had splint therapy in addition to orthognathic surgery (Table 10). A history of splint therapy prior to surgery would indicate that there may have existed some joint symptoms during the course of treatment.

If a history of trauma was recorded in the chart then it was positively indicated in the study. Other studies[19] have noted trauma as being a risk factor for TMD, ironically in this study trauma (Table 3) was found to be increased among those with mild or no resorption but not among those with severe resorption. It is possible that mild trauma may induce only small condylar change whereas those with severe resorption have a greater propensity for increased resorption despite a history of trauma. Nevertheless, severe trauma indicating condylar fractures was not found to exist among any of the groups. The number of those reporting trauma however, was small and is retrospective in nature as information was collected by reviewing patient charts, therefore no standards were set for obtaining a history of trauma from subjects at the time of treatment.

Disc displacement (DD) was not recorded either as this study is retrospective in nature. This would have been beneficial as CR has been cited[106] as being more common among those with a history of disc displacement and no pain than those with DD and pain or those without DD. It is suggested that people with DD and no pain have increased joint load and energy density or condylar pressure in multiple positions compared to those with pain or no DD. Increased joint loading may increase tissue stress which could cause cartilage breakdown and lead to bony condylar change.[106]

A posteriorly inclined condylar neck has been mentioned in the literature by Hoppenrejis et al as being associated with an increased risk of PCR after surgery.[77] The inclination of the condylar neck was not measured in this study as a number of subjects had condyles missing completely. Hwang et al.[96] also found that patients experiencing CR had statistically greater posterior inclination of the condylar neck (24.8± 6.9 degrees) compared with a control group (10.6 ± 14.7). However, the range of condylar inclination in this study was wide. The greatest inclination of the condylar neck in the group without CR was almost twice as great as the average inclination in the group with CR. This implies that CR is not caused by a posteriorly inclined condylar neck alone. Patients with increased facial height have a greater tendency toward a posterior inclined condyle, suggesting that the two factors are interrelated.[96]

Treatment duration (Table 2) in the control measured 31 ± 11 months whereas among those with the most resorption measured 40 ± 17months. Although there is a significant difference (p= 0.002) among the groups it is worth pointing out that the standard deviation is larger than the differences between the means. However, the general trend showed that the longer the treatment, the more severe the condylar resorption. This is in agreement with Peltola et al who concluded that resorption increases with treatment duration.[78]

Pain did not appear to be correlated with CR in this study (Table 3). Only three subjects or 6% in the most severe CR group reported pain at any time during treatment. This may be explained by Wiese et al.[92] who found that pain was not associated with increased risk of degenerative findings in TMJ tomograms. Although Kurita et al.[93] showed that some association does exist as a higher prevalence of joint pain on function was observed in joints with radiographic evidence of bone changed at the articular surface than in those without.

Many treatment factors or modalities were recorded for each subject in an effort to identify any association with CR, if one happened to exist. Headgear is a common treatment modality to correct Class II occlusion yet no significant association was found to exist among those who wore HG. Conversely, Peltola et al[78] found that the frequency of condylar pathosis to be 24% in a group treated with headgear.

Other methods of Class II correction involve Class II elastics or a functional appliance (Table 3). Many patients will report pain while wearing elastics. This may concern some clinicians that pressure or force is being placed on the joint and causing a potential for damage. In this study more than one half of all subjects wore Class II elastics, however, there was no significant association found between the groups for those who wore Class II elastics or a functional appliance and those who did not. Peltola et al[78] found the frequency of radiographic condylar pathology was 35% in a group treated with an Activator, and 11% for a Functional corrector. Ruf and Pancherez[94] found in a four year follow-up study after Herbst treatment that the clinical signs and symptoms of TMD were within the range of normal reported in the literature and the frequency of disc displacement was not higher than in asymptomatic populations.

Intriguingly, there was a difference among those who wore Class III elastics (Table 3). Ten subjects or 16% of Group A wore Class III elastics, 17 subjects or 28% of the Group B wore Class III elastics and only five subjects or 10% of Group C wore Class III elastics. The difference was not statistically significant for Group B (p= 0.043) but there is a large difference in percentage among the groups that is likely clinically significant. As Group C had increasingly severe skeletal deformity and a much higher prevalence of orthognathic surgery, it is possible that more attempts to camouflage the malocclusion were made in Group B than in Group C thus necessitating the use of more Class III elastics whereas in Group C surgery was used more frequently. If subscribing to the etiological theory of compressive forces on the joint, Class III elastics may have been enough to result in mild bony condylar remodeling whereas surgery may have resulted in more severe resorption. Condylar resorption (CR) and condylar remodeling (CRm) can both be observed following orthognathic surgical procedures. The distinguishing feature between them is that morphologic condylar changes in CR are associated with a reduction in ramal height, downward and backward rotation of the mandible, an increase in overjet and thin finger-like condyles. Condylar remodeling is an adaptive bone response to new forces placed on the condyle following surgery and is not associated with skeletal relapse.[61] Flattening of the condyle may appear but results in zero or only limited change of centric occlusion.[72] This would still allow for significant differences in skeletal characteristics to be identified between the groups.

Premolar extractions and its association with TMD has been explored extensively in the literature.[95] Since a 1987 Michigan lawsuit, great effort has been made to identify any association between the two. This study agrees with research already established [95] indicating no link between extraction treatment and TMD. No significant differences exist among the groups as 49% of the control had extractions, 43% of the mild group and 46% of the most severe CR group had premolar extractions (Table 3).

Treatment variables also showing no significant association with CR include congenitally missing teeth, palatal expansion, RPE or quad helix, bite plate and impacted canines (Table 3).

The number of females with CR in Group C was higher than the number of males. In other studies,[96] CR has a higher prevalence among young females than males. It is important to note that although the number of females receiving orthodontic and orthognathic surgical treatment is greater than males, proportionally the number of females affected is still higher.[96,61,69] A factor to consider when assessing sexual predilection is the possibility of a higher prevalence of TMJ dysfunction among females. In this study 62% of subjects with moderate to severe CR were female, 32% were male which is roughly a 2:1 female to male ratio.

Condylar resorption may affect patients within a large age range but more commonly affects younger patients. Hwang et.al[96] found that the group of surgery patients affected by CR was significantly younger (mean age 19.8 yrs +/-3.8yrs) than patients not affected (mean age 25.4yrs +/- 8.5yrs), but the two groups were not matched for skeletal discrepancy and the type of fixation used. Evidence by Borstlap et al[97] also suggests that teenage patients are more commonly affected than older individuals; however these younger patients may have more severe skeletal discrepancies to begin with. Cutbirth et al[10] found no age difference between patients suffering from CR and those who did not. One complication noted was that the majority of orthodontic and orthognathic surgery is undertaken in patients in their early 20's, making the sample size in other age groups small and therefore more difficult to realistically compare.

Of all of the treatment modalities accounted for in this study, the most highly statistically significant finding of those subjects who had moderate to severe CR was a history of orthognathic surgery (Table 3). Of the fifty-two subjects in Group C, 14 (27%) demonstrated a history of orthognathic surgery. This suggests that surgery may be associated with condylar degeneration or, on the other hand, that condylar degeneration may occur irrespective of orthodontic treatment thereby causing skeletal malformations that require an orthognathic surgical correction. Conversely, thirty-eight subjects or 73% had moderate to severe CR without a history of orthognathic surgery. Given that this study spans over a period of many years during which time various surgical techniques have come and gone, surgical technique was not standardized for this study. In current studies, non-compressive orthognathic surgery has been advocated to help reduce the risk of CR.[69,70,85] Despite the high incidence of orthognathic surgery among the group with the most severe condylar resorption, the CR occurring in the remaining subjects must indicate that there are other contributing factors. Other contributing factors in the development of CR following orthognathic surgery are age, sex, high pre-operative mandibular plane angle, facial morphology, stretching of soft tissue, fixation method, rotation of proximal segment amount of advancement and surgeons experience.[85] In the present study, groups were equally matched for age and sex that remove any confounding variables. Perhaps vertical facial pattern results in smaller, thinner condyles with less articulating surface area leading to increased joint compression. Additionally, the vector of muscle pull might be a factor in vertical patients as an increasingly direct line of force over the condylar head may be present as dolicofacial skeletal pattern increases. Conversely, Proffit[99] states that muscle strength is said to be decreased in dolicofacial subjects and implies that the differences in occlusal force in adults result from failure of the long-face group to gain strength during adolescence, not to the long face condition itself.

Due to the fact that orthognathic surgery was by far the most significant orthodontic treatment modality among those with moderate to severe CR, a sub-group analysis was performed comparing subjects with a history of orthognathic surgery to those without a history of orthognathic surgery (Table 9, 10). In an attempt to identify any correlations between those with surgery and those without surgery, orthodontic treatment modalities and cephalometric measurements which were significant or otherwise notable from Groups A, B and C, were compared between a surgical group and a non-surgical group.

The pre-treatment vertical facial pattern among those with CR and orthognathic surgery was not statistically significant from those without a history of surgery. However, if the present study had possessed a larger sample giving it greater power, this could have been clinically significant due to the magnitudes of the measurement differences. The surgery group demonstrated an increase in MP-SN, SN-PP angles, and a decrease in Facial Axis indicating a more overall dolicocephalic skeletal profile in the surgery group (Table 9). However, SN-OP, Gonial angle and P-AFH ratio were not found to be statistically significant when compared with those who had orthognathic surgery (Table 9). This is not surprising as the type of surgery was not compared. Since surgery can be used to correct a variety of craniofacial abnormalities, there were likely subjects who received orthognathic surgery who did not exhibit these craniofacial characteristics. Moore et al.[84] who did an extensive review of the literature on surgical relapse with special emphasis on condylar resorption found that the surgical group with the highest risk of condylar resorption was women 20 to 30 years of age with high mandibular plane angles and signs and symptoms of temporomandibular dysfunction. All of the patients in that study[84] with condylar resorption had a high mandibular plane angle pre-operatively (SN-MP ≥40°). The mean MP-SN in the surgical group of the present study was 38.34 and the mean among the non-surgical group was 34.77 (Table 9). Kerstens et al.[7] showed condylar resorption after bimaxillary surgery limited to patients possessing mandibular hypoplasia with a high mandibular plane angle. Conversely, Will and West[88] analyzed facial morphology and its value for predicting mandibular relapse following BSSO. They found no relationship between any of the measurements of facial morphology and relapse.

A large magnitude of measurement difference found among Groups A,B and C among those with a history of orthognathic surgery showed more upright lower incisors, decreased SNB and increased Wits (Table 9).

Condylar resorption has been implicated in many studies evaluating skeletal stability following orthognathic surgery, particularly mandibular advancement surgery. Sheerlink et al[13] found that of those receiving BSSO advancement surgery with plate and screw fixation, 8/103 or 8% of subjects had progressive condylar resorption, four of which had complete disappearance of the condyle with 20% developing increased pain and/or clicking. Doyle[87] found that 9/27 or 33% receiving orthognathic surgery showed active postsurgical condylar changes. Kau et al[108] reported CR in 5-10% of patients who undergo orthognathic surgery using 3D imaging technology. In the present study, of the 22 subjects who received orthognathic surgery, 18 subjects or 82% had some form of observable CR. These surgeries took place between the years of 1983 and 2007 where a variety of surgical techniques and fixation methods were likely employed. The type of surgery was not noted, nor was the amount of correction or the type of fixation used. It is also important to mention that 14 of the 22 surgery subjects were part of Group C, which were selected from all 2018 subjects in effort to identify those with the most resorption.

The type of surgical correction was not noted in this study but could be a direction for future research. Merkx and Van Damme[103] demonstrated that condylar resorption appeared in subjects only after sagittal splitting and not after LeFort I osteotomy alone. Finn et al[104] state that superior positioning of the maxilla by a LeFort I osteotomy, either with or without sagittal splitting of the ramus, will always result in autorotation of the condyes so that the more anterior part of the articular surface will be loaded. Kerstens et al[7] study demonstrated that in surgically corrected subjects the greatest amount of bone loss was seen in the anterior condylar surface, which has been in contact with the articular eminence. An imbalance between stresses applied to the joint and the joints ability to tolerate that stress could give rise to osteoarthrosis.[7] A recent study cited that 93% of subjects had discs that were not positioned correctly post-surgery with 76% of subjects showing condylar displacement.[107]

Condylar change over time

Subsequent to selection of groups and evaluation of initial statistics, a secondary post hoc effort was made in attempt to quantify the amount of condylar change that occurred in the individual subjects and any association with skeletal characteristics or treatment modalities. In order to draw firm conclusions, further investigation would be warranted and could be the direction of future research. In this study, subjects with moderate to severe condylar resorption had a more dolicofacial skeletal pattern than those in the other groups. These same subjects also had an increase in prevalence in orthognathic surgery. In order to explore the relationship between orthognathic surgery and condylar resorption (CR) and help illuminate whether significant CR occurred due to a history of surgery or whether it occurred simply because patients exhibited a more pretreatment dolicofacial skeletal pattern, this post hoc effort was undertaken to help clarify the ambiguity of this chicken and egg question.

Observations only are made from the new categories based on the change of initial and final condylar score from T1 to T3. There were 21 possible categories in total, but only 15 categories resulted in at least one subject (Figures 75-77).

Category A had the largest number of all the categories with a total of 61. By convention, this was Group A of the original three Groups A, B and C and thus is defined by no condylar change indicated by a condylar score of 0 at T1 through T3 (Figure 76). Surprisingly, the second largest category overall but the largest category exhibiting condylar change was Category E with 26 subjects. Category E represents a large change in condylar score from 0 at T1 to 3 at T3, representing a bony condylar change starting at normal and progressing to at least 50% of the condyle being resorbed. The third largest category was Category C with 20 subjects representing a minor change in condylar score from 0 at T1 to 2 at T2 (Figure 76). It was unexpected that Category E representing such an extensive amount of condylar change would include such a large number of subjects. It is worth mentioning that condylar change results in a decrease in condylar dimensions or area among the groups and not an increase. An increase in condylar dimension was not found to exist in any of the subjects in this study. An increase in condylar dimension has been demonstrated in studies of osteoprotegerin-deficient mice receiving bisphosphonate treatment.[100] However, none of the subjects had any record of taking any type of bisphosphonate medication.

The amount of condylar change over time was also compared among those that had orthognathic surgery. Of 22 subjects with a history of orthognathic surgery, 8 or 36% were found to be located in Category E signifying those who started out at a condylar score of 0 or no resorption and progressed all the way into the moderate to severe category of 3 where at least 50% and up to 99% of the condyle was resorbed. One subject had a change from 0 to 4 indicating a complete loss of condyle. Of all those who had orthognathic surgery, only four out of 22 showed no condylar resorption.

Therefore, 82% of all patients having orthognathic surgery exhibited some degree of condylar resorption. Nine out of 22 surgical subjects or 41% (combination of Categories E and F) exhibited a large change in condylar resorption going from grade 0 at T1 to grade 3 or 4 at T3. These subjects exhibited no condylar resorption thus were considered normal at T1 and ended with moderate to severe resorption at T3. Upon inspection of these changes, categories were grouped together to help quickly visualize the amount of change that was occurring and whether the change was large or small (Table 12). Those categories demonstrating no change over time were all grouped together. Those demonstrating a mild change were grouped together, and those demonstrating change that is moderate to severe were grouped together. This helps resolve some of the weaknesses of this study. For example, a subject may have been placed in Group C because of a CR score of 3 at T3, however this subject may have had a CR score of 3 at T1 thus no change ever occurred over the course of observation which may be misleading. This particular example occurred in 3 subjects in category S and likewise occurred with other subjects in other categories.

It is important to point out that those with a CR score of 1 by definition exhibited very slight resorption such as a flattening of the condylar head. Those with a CR score of 2 exhibited resorption of the top of the condyle with up to 50% of the condyle resorbed. Those with a CR score of 3 by exhibited at least 50% but less than 100% of the condyle resorbed and those with a CR score of 4 exhibited 100% of the condyle resorbed. This means that there was a more severe amount of bony condylar change over time in subjects with a score of 2-3 (CR score T1-T3) than subjects with a score of 1-2 or even 0-2. The results of these categorical groupings (Table 12) indicated 14 out of 22 subjects exhibited a moderate to severe amount of condylar change with a history of orthognathic surgery or 63.64%. This was compared with 33 out of 152 subjects or 21.71% with the same degree of change but with no history of orthognathic surgery. This indicates that orthognathic surgery equals a relative risk for condylar resorption of three-fold (Table 12).

To further clarify whether orthognathic surgery was a cause of condylar resorption or whether it was performed due to the effect of CR on the craniofacial complex, additional statistics were evaluated. All those who presented with any CR other than zero at the initial time point (T1) were removed from the original 3 groups and the same descriptive statistics were analyzed. It was discovered that five percent of groups A and B respectively had a history of orthognathic surgery whereas 30% of group C had a history of orthognathic surgery. Therefore a statistically significant increase of orthognathic surgery is observed in group C. Additionally, to help determine whether the grade of condylar resorption had any influence on whether orthognathic surgery was performed, the same subjects having a history of CR at T1 were again removed. Those with a history of orthognathic surgery and those with no history of orthognathic surgery were compared by the grade of condylar resorption at T2 (deband). No statistical significance was found to exist between the surgical and non-surgical groups indicating that orthognathic surgery was likely performed independent of the grade of condylar resorption.

As the primary intent of this study was to provide a comparison among the groups in order to identify significant differences between skeletal characteristics, dental characteristics and treatment related modalities for those with moderate to severe CR and to identify risk factors for CR by observing condylar change over time, the study purpose has been fulfilled. Futher investigation is warranted regarding condylar change over time and could be the topic of future research but is beyond the scope of this present study.

The null hypothesis that there is no difference in vertical skeletal morphology as characterized by the four measurements: MPA, AFH/PFH ratio, gonial angle, Rickett's facial axis between the condylar resorption groups was rejected.

The null hypothesis that there is no difference in anterior-posterior skeletal morphology as characterized by the four measurements: ANB, SNB, facial convexity, Pg-Na perpendicular demonstrating Mn retrognathia between the condylar resorption groups could not be rejected as only SNB showed a significant difference between the groups. Pg-Na perpendicular although not statistically significant showed a large measurement difference between the groups, the only caveat being large standard deviations that are greater than the differences between the means.

The null hypothesis that there is no difference in dental measurements: OJ, U1-PP, L1-MP was not rejected as there was no difference among the groups in upper incisor proclination. However, subjects with moderate to severe CR showed more retroclined lower incisors and increased overjet compared with controls.

The null hypothesis that there is no difference relating to a history of trauma, splint therapy, TMJ or muscular pain during treatment, or differing modalities of orthodontic treatment such as CL II, III elastics or orthognathic surgery between the condylar resorption groups could not be totally rejected. There was a significant difference however for those subjects with a history of orthognathic surgery, the results of which show a relative risk of three fold in moderate to severe CR. Additionally, a trend was observed which demonstrated that an increase in treatment length seemed to indicate a greater severity of CR.

Conclusions

The conclusions from this study are as follows:

1. Subjects exhibiting a pre-treatment vertical skeletal profile as identified by an increased SN-MP, gonial angle, P-AFH and decreased facial axis demonstrate an increased severity of CR post-treatment.
2. Subjects demonstrating greater differences in AP skeletal morphology as seen in subjects with skeletal Class II characteristics showed no greater severity in condylar resorption than those who had normal AP skeletal morphology.
3. Subjects with increased overjet and lower incisor retroclination demonstrated an increased severity of CR post-treatment.
4. Subjects with a history of orthognathic surgery showed three-fold relative risk of moderate to severe condylar resorption compared to those without a history of orthognathic surgery.
5. Subjects with increased treatment length show an increased severity of CR.
6. Eighty-two percent of subjects with a history of orthognathic surgery show some degree of condylar change. Sixty-four percent of subjects show a moderate to severe amount of condylar resorption from initial to two years post deband.

It seems apparent that those subjects with a history of orthognathic surgery, a dolicofacial skeletal pattern with upright lower incisors and increased overjet and extended treatment times have an increased association with condylar resorption. The presence of skeletal Cl II malocclusion does not seem to indicate any increased association, rather a retrusive mandible and maxilla is characteristic.

Tables

Table 1. Treatment Groups

2018 total UWO archived patients			
Group	A	B	C
Sample selected in Part I	0	0	61

1957 remaining UWO archived patients			
Group	A	B	C
Sample selected in Part II	61	61	0
Subjects dropped for exculsion criteria	0	0	9
Final n per group	61	61	52

Table 2. Subject Demographics

Subject Demographic	Group A: Control Mean (SD) or (% of group)	Group B: mild Mean (SD) or (% of group)	Group C: moderate-severe Mean (SD) (% of group)	p value
Total number	61	61	52	NS
Males	26 (43%)	22 (36%)	20 (38%)	NS
Females	35 (57%)	39 (64%)	32 (62%)	NS
Race (Caucasian)	59 (97%)	59 (97%)	51 (98%)	NS
Age at initial	13.5 (3.7)	14.4 (4.8)	13.8 (3.7)	NS
Age at deband	16.1 (3.6)	17.3 (4.7)	17.3 (3.4)	NS
Treatment duration	2.6 yrs (10.7mo)[a]	3.0 yrs (13.5 mo)[a,b*]	3.4 yrs (17.4 mo)[b]	0.002

Table 3. Treatment variables

Treatment variable	Group A (% of group)	Group B (% of group)	Group C (% of group)	p value
Headgear	27 (44%)	27 (44%)	17 (40%)	NS
Functional appliance	4 (7%)	1 (2%)	5 (10%)	NS
Class II elastics	35 (57%)	40 (66%)	32 (62%)	NS
Class III elastics	10 (16%)	17 (28%)	5 (10%)	p= 0.0431
Orthognathic surgery	3 (5%)	5 (8%)	14 (27%)	p= ≤0.001
Premolar extractions	30 (49%)	26 (43%)	24 (46%)	NS
Splint therapy	1 (2%)	2 (3%)	6 (12%)	p= 0.043
TMJ or muscular pain during tx	2 (3%)	6 (10%)	3 (6%)	NS
Congenitally missing teeth	1 (2%)	0 (0%)	3 (6%)	NS
Bite plate	5 (8%)	7 (11%)	4 (8%)	NS
Palatal expansion (RPE or quad helix)	6 (10%)	10(16%)	8 (15%)	NS
Impacted canines	0 (0%)	4 (7%)	2 (4%)	NS
History of orofacial trauma	8 (13%)	6 (10%)	0 (0%)	p= 0.0312

Cephalometric characteristics

Table 4. Soft tissue profile measurements

Measurement of *Soft Tissue Profile*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
Nasolabial Angle (°)	109.6[a] (9.2)	110.0[a] (8.5)	114.7[b] (9.1)	p= 0.0049
Facial Angle (FH-NPo) (°)	86.8[a] (2.8)	86.7[a] (3.2)	85.8[a] (3.3)	NS
Facial Convexity (A-NPo) (mm)	3.1[a] (3.1)	2.6[a] (2.5)	3.2[a] (2.7)	NS
Lower lip – E Plane (mm)	0.12[a] (3.3)	-0.06[a] (3.0)	-0.68[a] (3.3)	NS

Table 5. Cranial base measurements

Measurement *Cranial Base*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
NSBa (°)	143.4[a] (9.0)	145.7[a] (6.6)	130.5[b] (4.3)	p= <0.0001

Table 6. Skeletal Measurements

Measurement *Skeletal*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
SNA (°)	83.5^{a} (4.4)	83.3^{a} (4.1)	80.1^{b} (3.3)	p=<0.0001
SNB (°)	79.1^{a} (4.0)	79.2^{a} (4.0)	75.7^{b} (3.5)	p=<0.0001
ANB (°)	4.4^{a} (2.9)	3.8^{a} (2.3)	4.4^{a} (2.2)	NS
A-Na perpendicular (mm)	0.2^{a} (3.8)	-0.3^{a} (3.5)	-1.0^{a} (3.4)	NS
Pg-Na perpendicular (mm)	-5.7^{a} (5.4)	-5.5^{a} (6.3)	-7.9^{a} (6.3)	NS
Wits (mm)	$1.3^{a,b}$ (3.0)	0.9^{a} (3.4)	2.6^{b} (3.9)	p=0.0225
Maxillary Length (Co-A) (mm)	85.7^{a} (4.8)	85.7^{a} (4.9)	84.5^{a} (3.9)	NS
Mandibular Length (Co-A) (mm)	118.1^{a} (7.6)	118.7^{a} (7.4)	116.4^{a} (7.7)	NS
Mx/Md Difference (mm)	31.9^{a} (5.8)	32.4^{a} (5.9)	27.6^{b} (5.7)	p=<0.0001
Articular Angle (S-Ar-Go)	143.4^{a} (9.0)	145.7^{a} (6.6)	130.5^{b} (4.3)	p=<0.0001

Table 7. Dental Measurements

Measurement *Dental*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
U1-SN (°)	105.3^{a} (8.5)	105.3^{a} (9.1)	103.9^{a} (8.6)	NS
U1-NA (°)	22.0^{a} (8.6)	22.3^{a} (8.8)	23.7^{a} (8.2)	NS
U1-NA (mm)	4.5^{a} (3.3)	4.8^{a} (3.1)	5.5^{a} (3.0)	NS
U1-PP (°)	108.9^{a} (7.6)	109.6^{a} (8.3)	140.3^{b} (7.7)	p=< 0.0001
U1-L1 (°)	128.0^{a} (12.7)	128.8^{a} (10.8)	130.1^{a} (11.4)	NS
L1-Apo (mm)	1.6^{a} (3.0)	1.7^{a} (2.5)	1.2^{a} (2.7)	NS
IMPA (°)	92.2^{a} (8.0)	92.7^{a} (5.9)	87.5^{b} (6.8)	p= 0.0003
Overbite (mm)	2.8^{a} (2.9)	2.8^{a} (3.0)	3.0^{a} (2.4)	NS
Overjet (mm)	5.8^{a,b} (2.7)	5.4^{a} (2.4)	7.1^{b} (3.6)	p=0.0099

Table 8. Vertical Measurements

Measurement *Vertical*	Group A (control) Mean (SD)	Group B (mild) Mean (SD)	Group C (moderate – severe) Mean (SD)	p value
Palatal Plane				
SN-PP (°)	3.6^{a} (3.2)	4.4^{a}(3.8)	7.3^{b} (3.2)	p= <0.0001
PP-MP (°)	31.0^{a} (6.2)	28.6^{a} (5.6)	31.1^{a} (5.5)	NS
PP-OP (°)	11.2^{a} (3.9)	9.9^{a} (3.3)	9.6^{a} (4.1)	NS

Occlusal Plane

SN-OP (°)	14.7[a] (4.2)	14.4[a] (4.2)	16.9[b] (4.8)	p= <0.0001
FH-OP (°)	7.8[a] (3.8)	7.6[a] (3.9)	8.0[a] (4.7)	NS

Mandibular Plane

SN-MP (°)	34.6[a] (6.2)	33.1[a] (5.8)	38.4[b] (5.4)	p= <0.0001
FMA (°)	27.6[a,b] (5.5)	26.4[a] (5.0)	29.5[b] (4.8)	p= 0.0046

Gonial Angle

Ar-Go-Me (°)	129.5[a] (8.5)	127.1[a] (6.5)	133.5[b] (7.1)	p= <0.0001
Ar-Go-Gn (°)	128.0[a] (6.5)	126.1[a] (5.4)	127.6[a] (4.8)	NS

Others

Ramus Height (Ar-Go) (mm)	42.6[a] (4.8)	44.0[a,b] (5.0)	45.3[b] (6.1)	p= 0.0046
Rickett's Facial Axis (°) Ba-Na^Pt-Gn	0.4[a] (4.5)	0.3[a] (3.7)	-2.3[b] (4.1)	p= 0.0001
Y-axis (Down's) SGn-FH (°)	59.5[a] (3.4)	59.5[a] (3.4)	60.0[a] (3.2)	NS
Y-axis SGn-SN (°)	66.5[a] (4.2)	66.2[a] (3.9)	69.5[b] (3.8)	p= <0.0001
AFH (NaMe) (mm)	115.4[a] (8.4)	115.4[a] (7.3)	118.8[a] (7.8)	NS
PFH (SGo) (mm)	73.8[a] (5.4)	75.5[a] (6.5)	73.8[a] (6.4)	NS
P-AFH (S-Go/N-Me) (%)	64.1[a] (3.8)	65.5[a] (4.8)	62.0[b] (4.3)	p= <0.0001
UFH (N-ANS) (%)	42.3[a] (2.6)	42.7[a] (2.3)	43.8[b] (2.2)	p= 0.0396
LFH (ANS-Me) (%)	57.7[a] (2.6)	57.3[a] (2.3)	56.2[b] (2.2)	p= 0.0396

Table 9. Cephalometric measurements by orthognathic surgery

Vertical measurements

Measurement	Orthognathic Surgery Yes Mean (SD)	Orthognathic Surgery No Mean (SD)	p value
MP-SN	38.34 (5.40)°	34.77 (6.18)°	p= 0.0110
MP-FH	4.48 (3.70)°	5.31 (4.27)°	p=0.0163
Facial axis	-2.49 (5.22)°	-0.16 (4.04)°	p=0.0163
P-AFH%	62.36 (3.50)°	64.19 (4.58)°	p= 0.0745 (NS)
SN-PP	6.87 (4.32)°	4.75 (3.60)°	p= 0.0129
SN-OP	16.49 (5.81)°	15.11 (4.27)°	NS
Gonial angle	132.97(7.97)°	129.45 (7.71)°	p= 0.0475

Anterior-posterior measurements

Overjet	7.38 (4.50)mm	5.85 (2.66)mm	p= 0.0110
U1-PP	130.10 (16.21)°	116.88 (15.63)°	p= 0.0003
L1-MP	87.83 (7.02)°	91.45 (7.22)°	p= 0.0286
SNA	80.41 (4.30)°	82.72 (4.20)°	p= 0.0171
SNB	75.96 (5.03)°	78.44 (3.93)°	p= 0.0083
ANB	4.15 (2.35)°	4.46 (3.49)°	p= 0.5758 (NS)
Wits	2.89 (4.16)mm	1.36 (3.34)mm	p=0.0552 (NS)

Cranial Base

SN-Ba	115.25 (11.11)°	123.80 (9.04)°	p= <0.0001

Soft Tissue

NLA Col-Sn-UL	115.80 (8.84)°	110.60 (9.07)°	p= <0.0001

Oneway Analysis of OP-SN By Group-Final

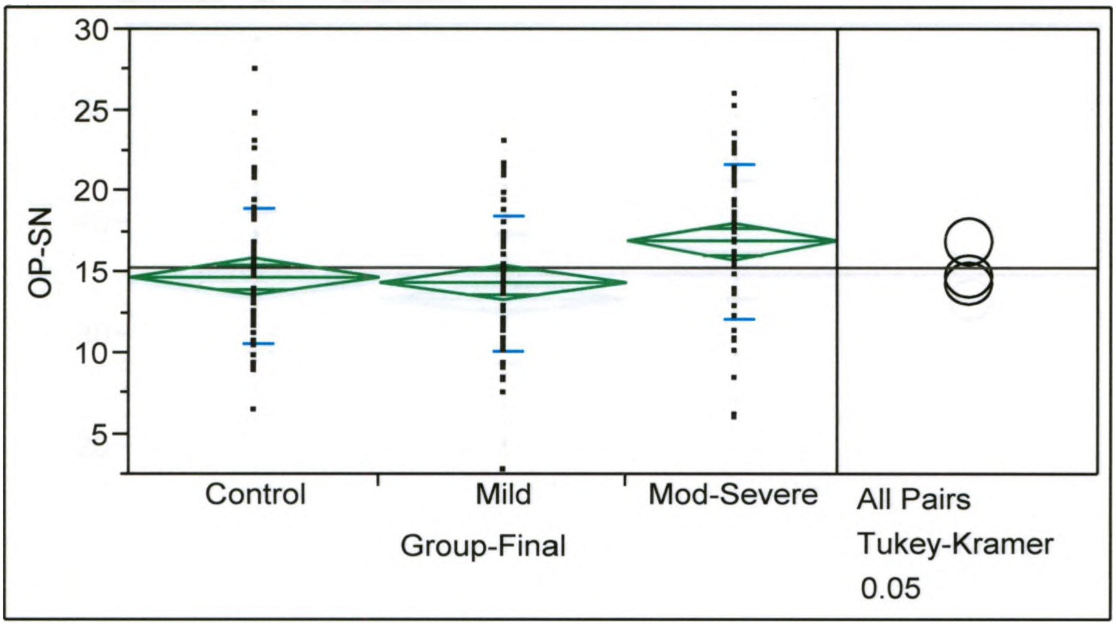


Figure 48. Association of OP-SN by group (p= 0.0065).

Oneway Analysis of MP-FH By Group-Final

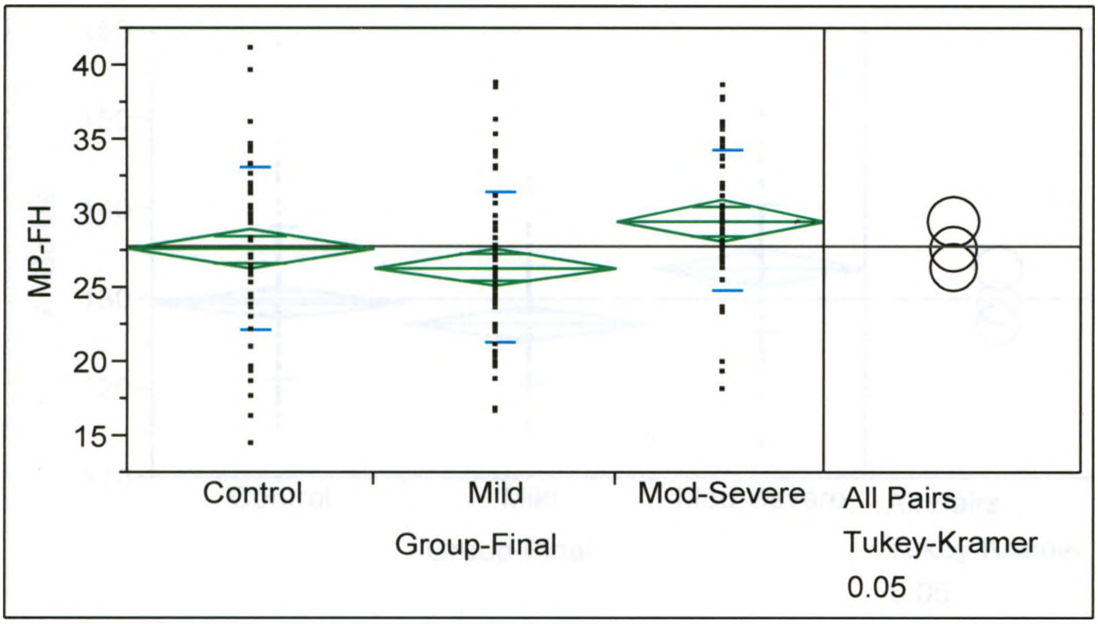


Figure 49. Association of MP-FH by group (p= 0.0046).

Oneway Analysis of MP-SN By Group-Final

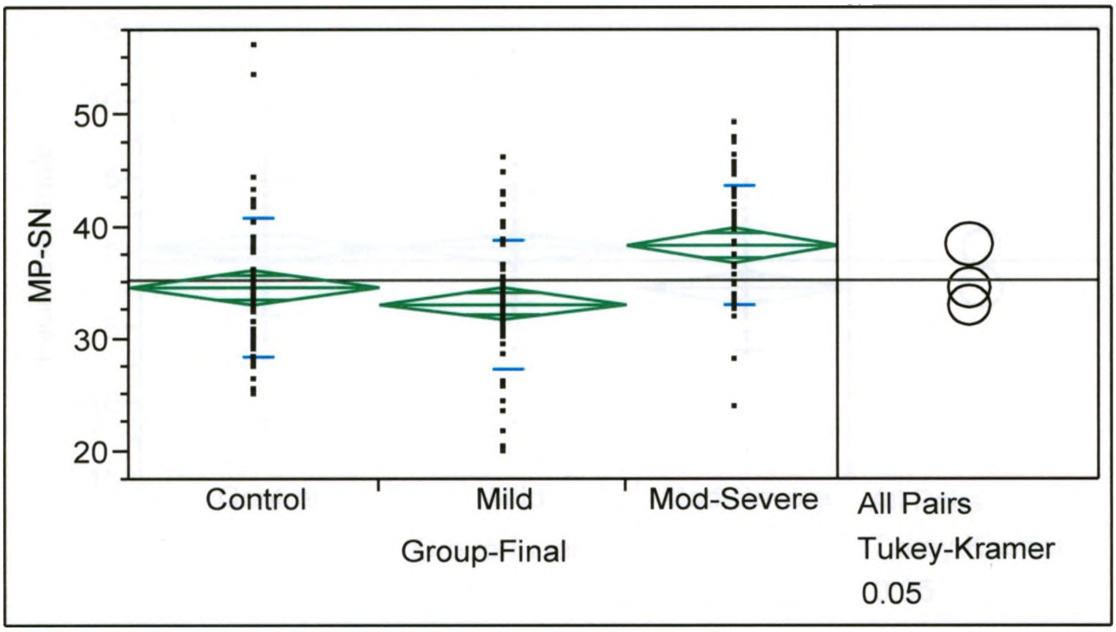


Figure 50. Association of MP-SN by group (p= <0.0001).

Oneway Analysis of Ar-Go-Me By Group-Final

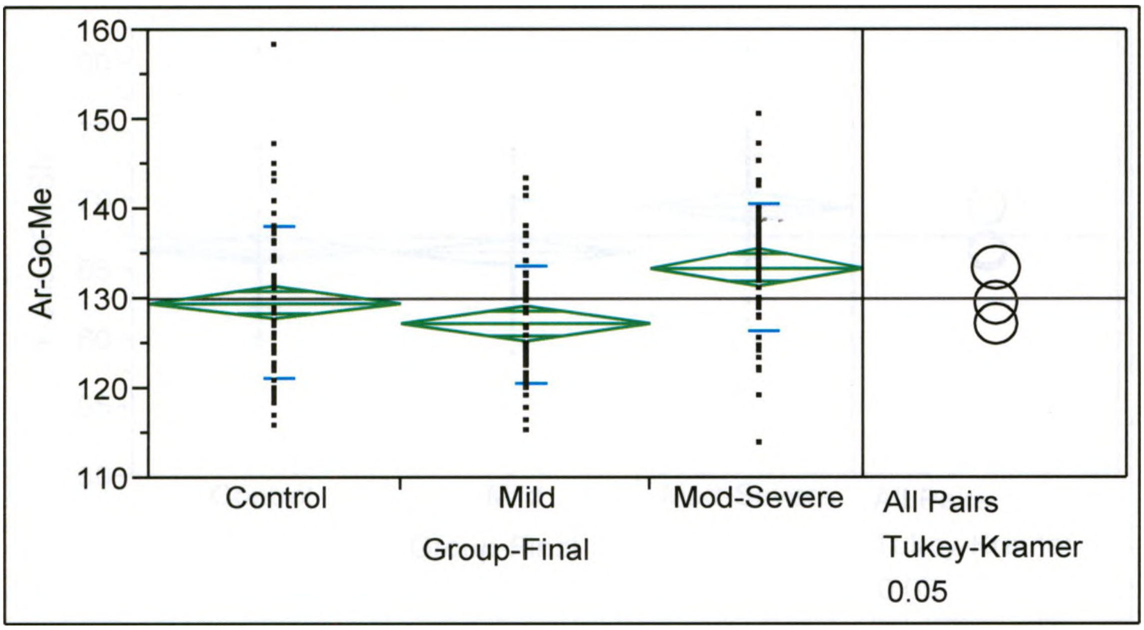


Figure 51. Association of gonial angle by group (p= <0.0001).

Oneway Analysis of Facial axis angle By Group-Final

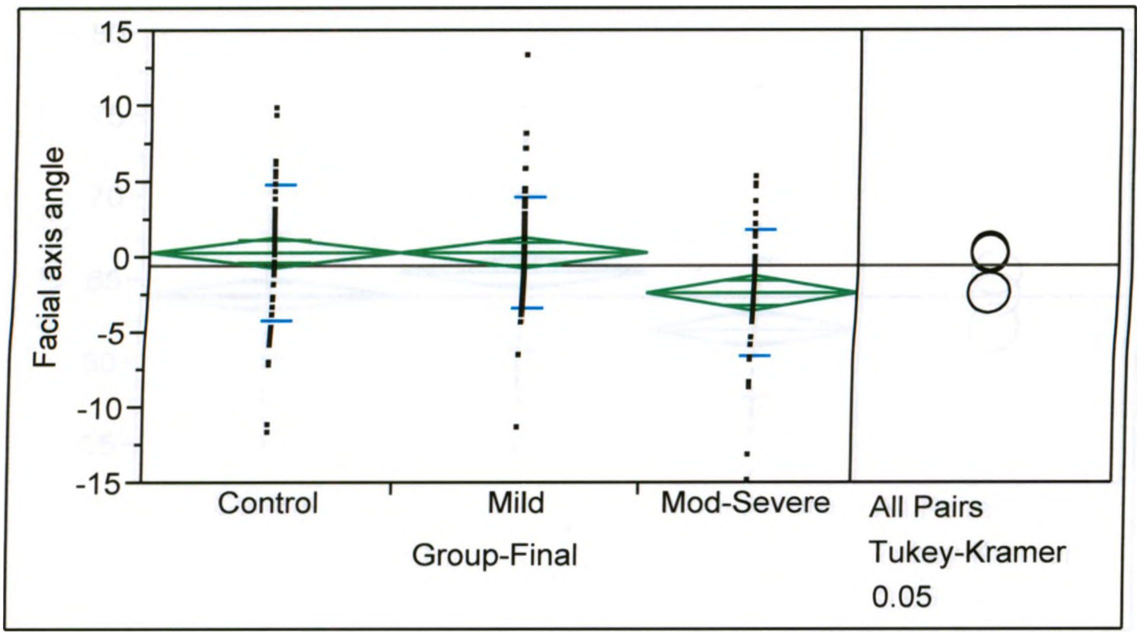


Figure 52. Association of Facial axis angle by group (p= 0.0023).

Oneway Analysis of Y-axis SGn-SN By Group-Final

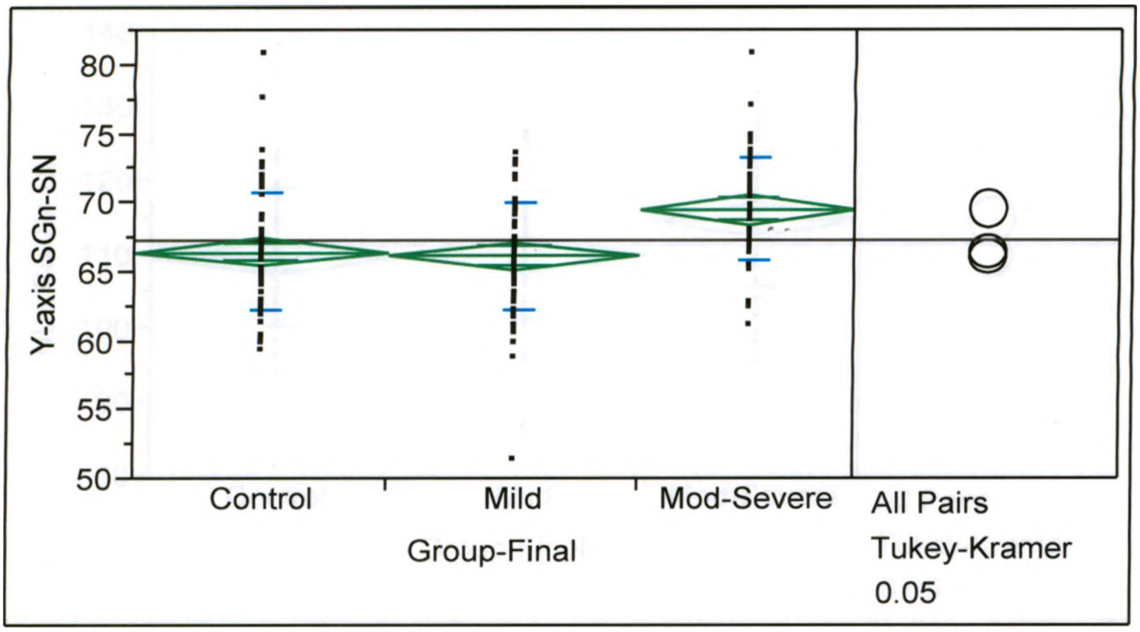


Figure 53. Association of Y-axis SGn-SN by group (p= <0.0001).

Oneway Analysis of P-AFH (%) By Group-Final

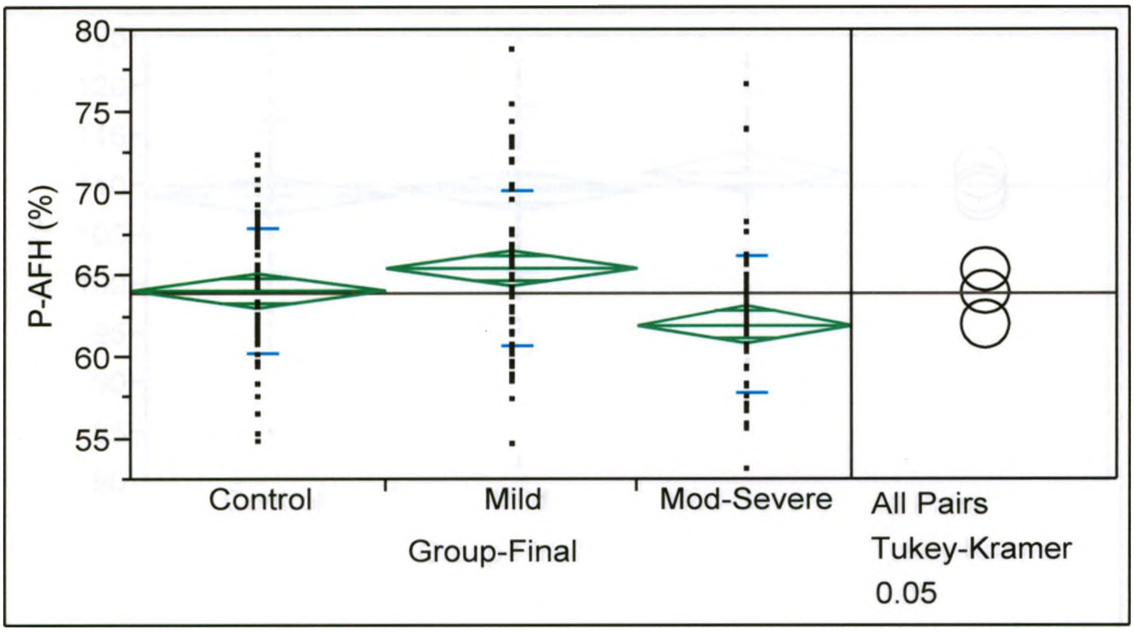


Figure 54. Association of P-AFH% by group (p= 0.0001).

Oneway Analysis of NLA Col-Sn-UL By Group-Final

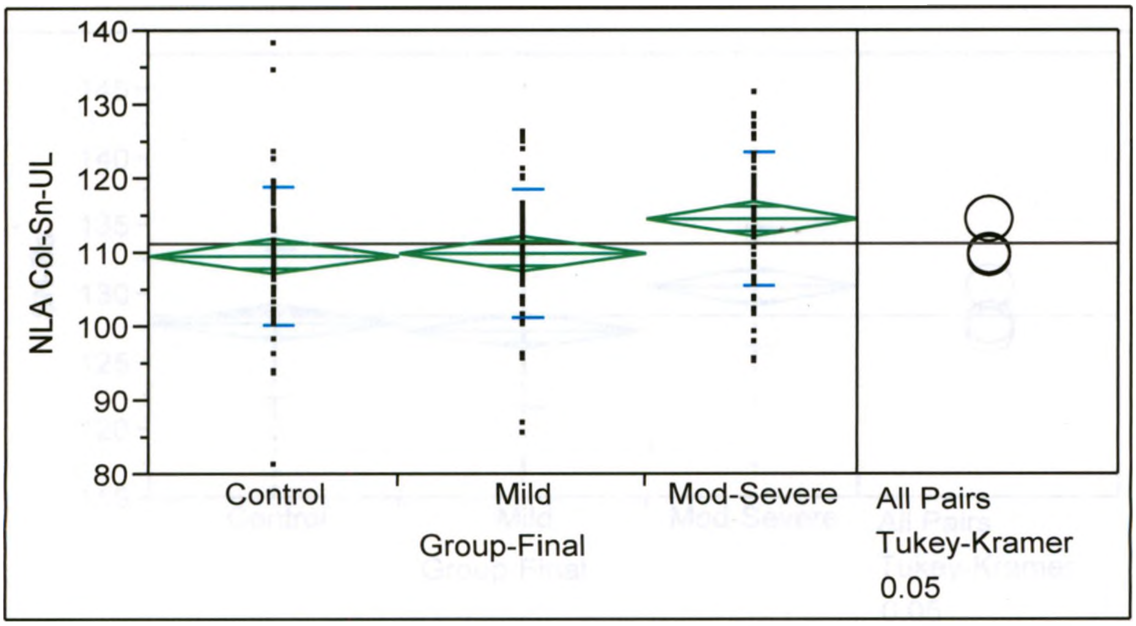


Figure 55. Association of Nasolabial angle by group (p= 0.0084).

Oneway Analysis of U1-PP By Group-Final

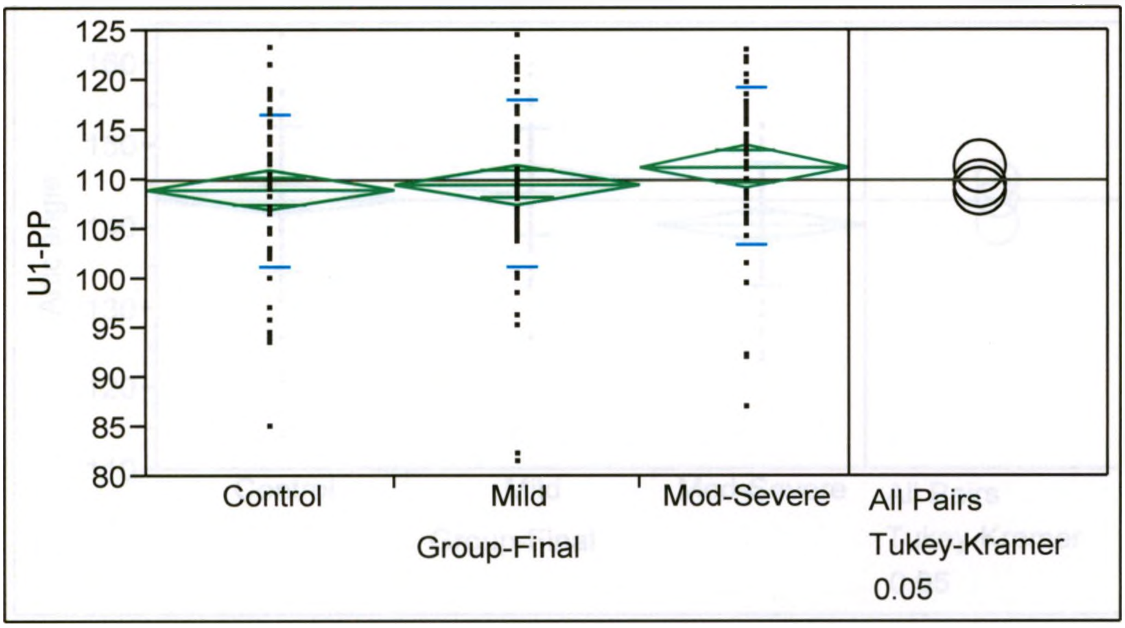


Figure 56. Association of U1-PP by groups (p= 0.239).

Oneway Analysis of SN-Ba By Group-Final

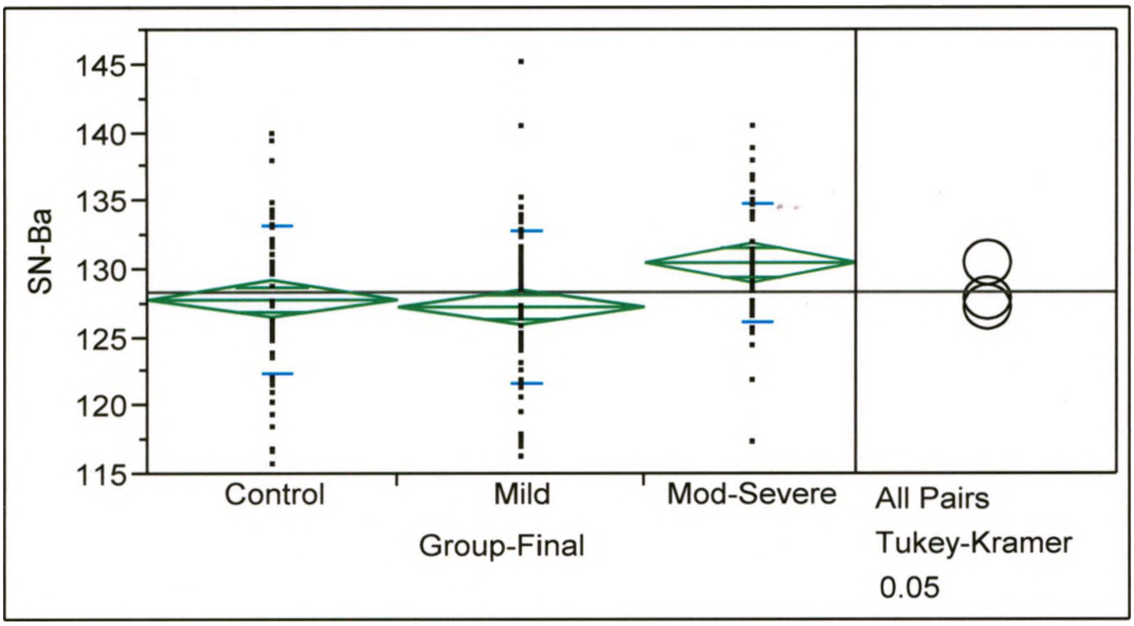


Figure 57. Association of cranial base angle by group (p= 0.0029).

Oneway Analysis of Artic angle By Group-Final

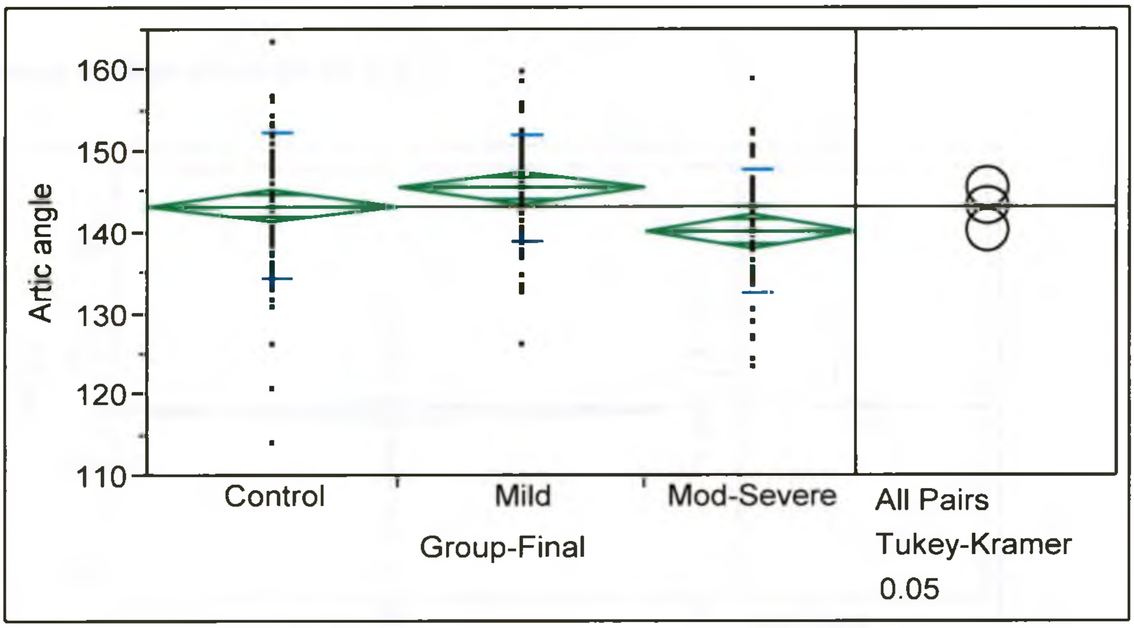


Figure 58. Association of articular angle (S-Ar-Go) by group (p= 0.001).

Associations by orthognathic surgery

Oneway Analysis of MP-SN By O.S.

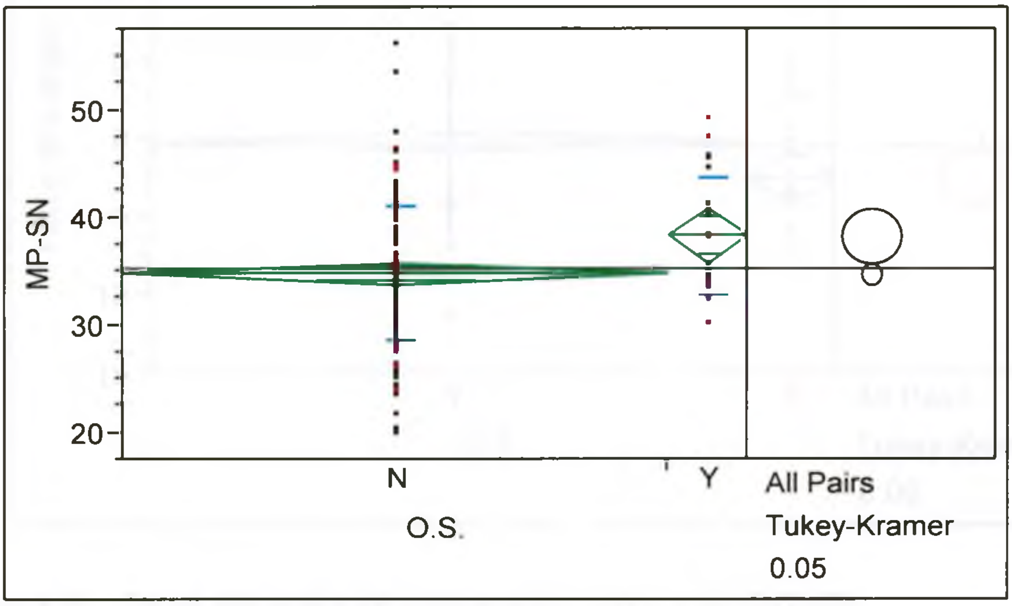


Figure 59. Mandibular plane to SN by orthognathic surgery (p=0.011).

Oneway Analysis of MP-FH By O.S.

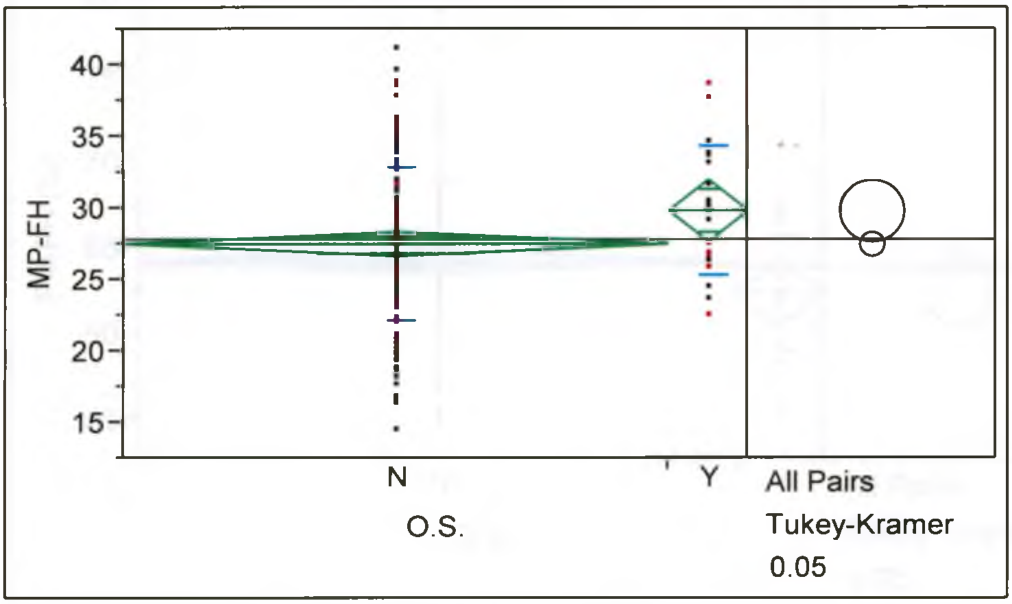


Figure 60. Mandibular plane angle-SN to orthognathic surgery (p= 0.0495).

Oneway Analysis of Facial axis angle By O.S.

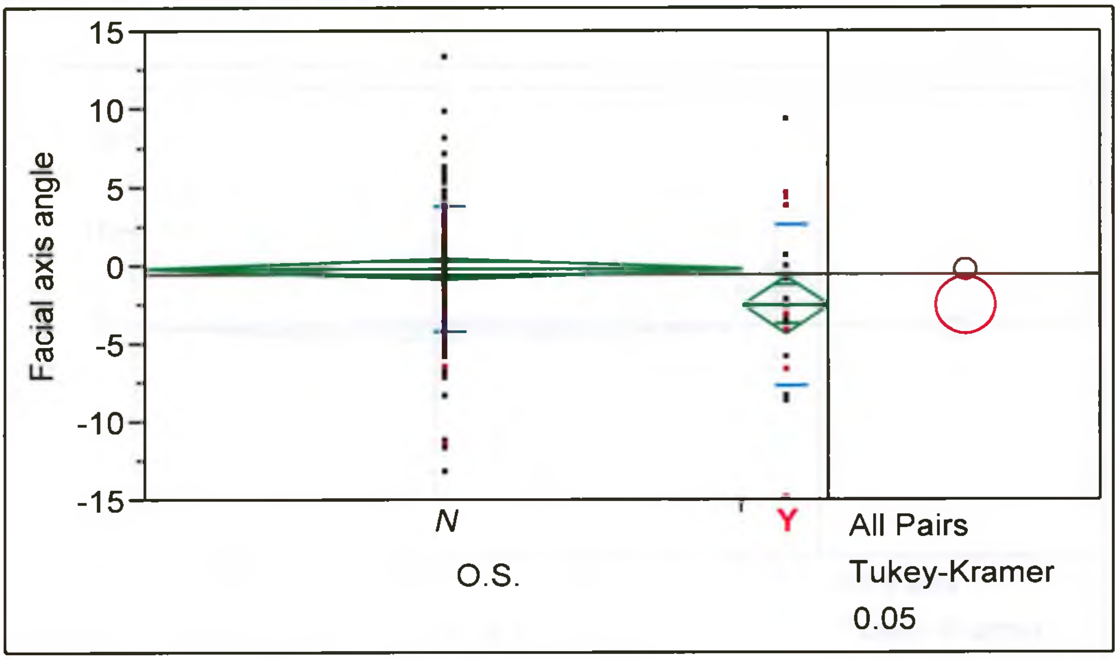


Figure 61. Facial axis angle by orthognathic surgery (p= 0.0163).

Oneway Analysis of P-AFH (%) By O.S.

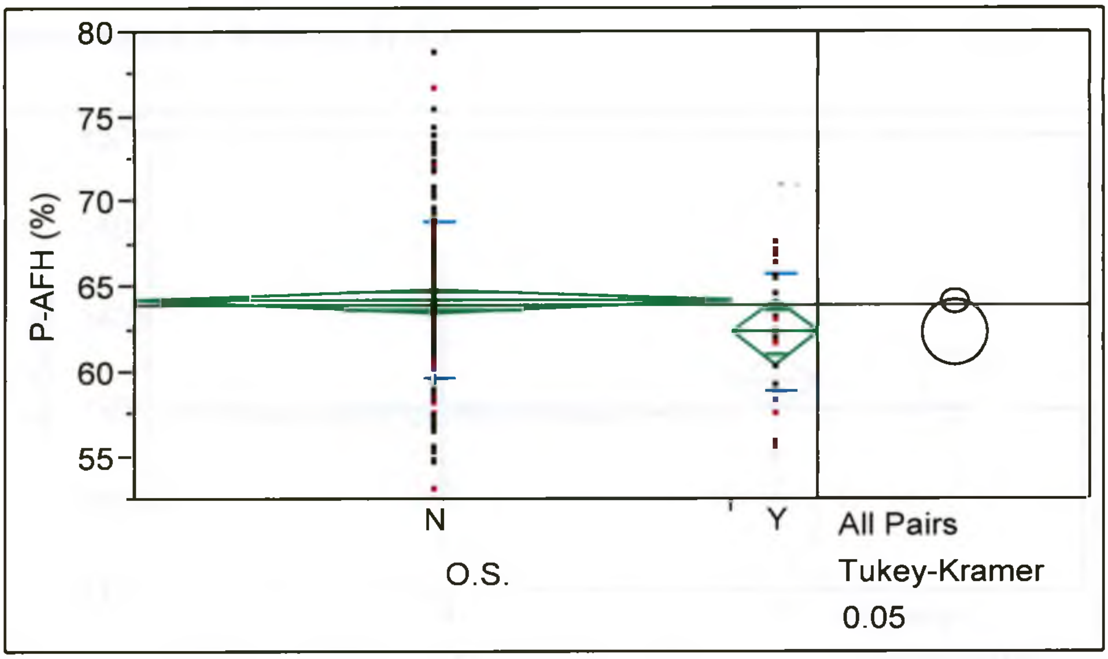


Figure 62. Posterior face height to anterior face height as a percentage by orthognathic surgery (p=0.075).

Oneway Analysis of SN-PP By O.S.

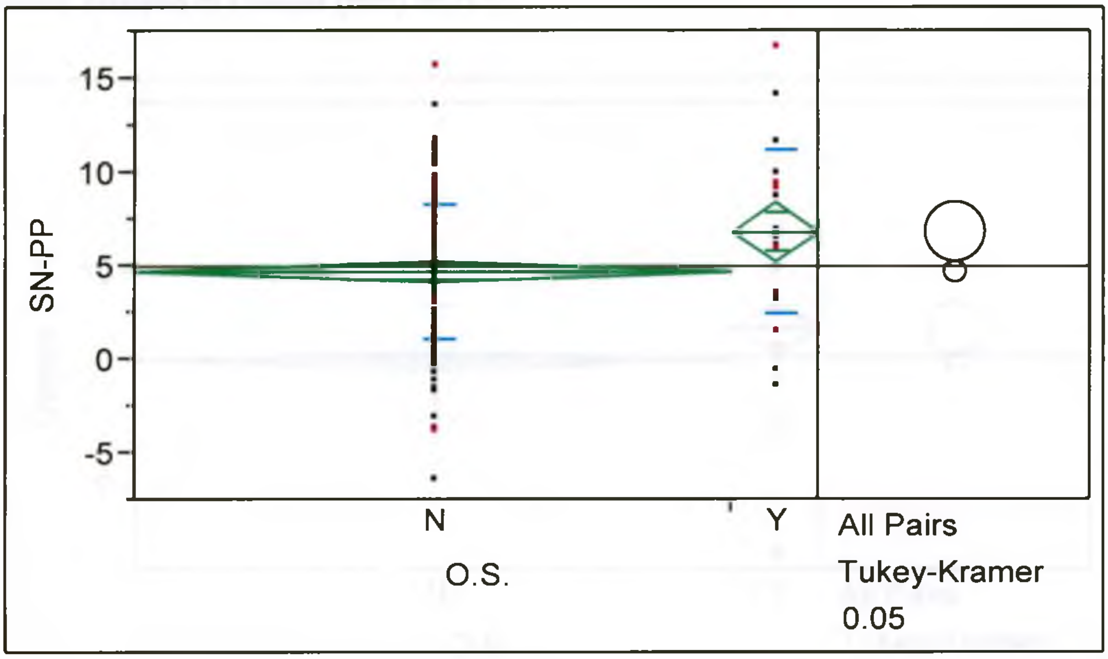


Figure 63. SN-PP by orthognathic surgery (p= 0.0129).

Oneway Analysis of Ar-Go-Me By O.S.

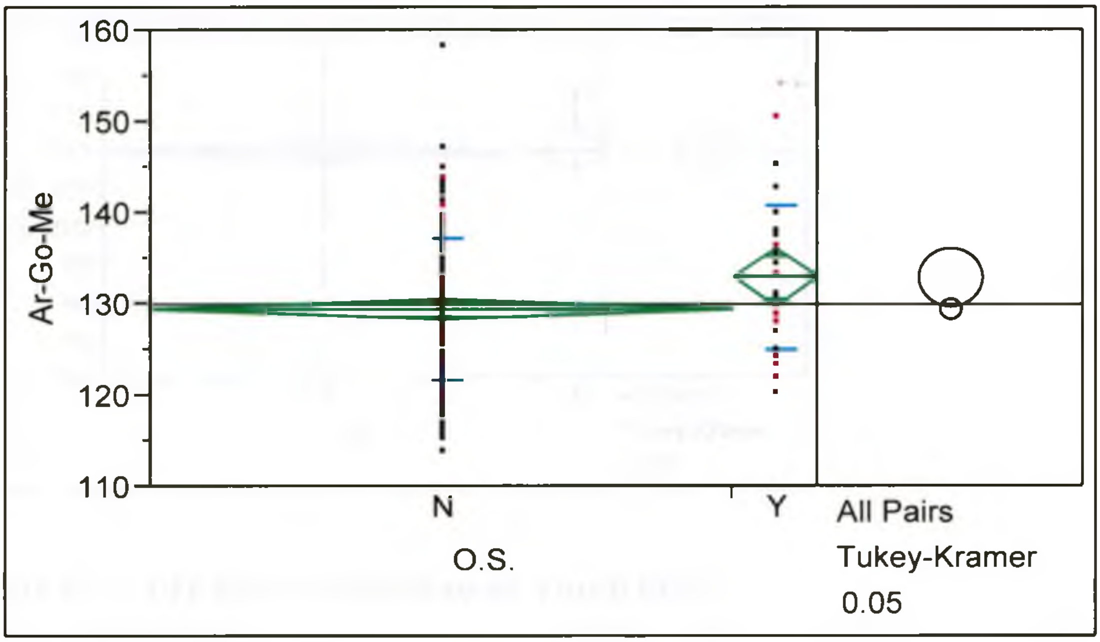


Figure64. Ar-Go-Me by orthognathic surgery (p= 0.0475).

Oneway Analysis of Overjet (mm) By O.S.

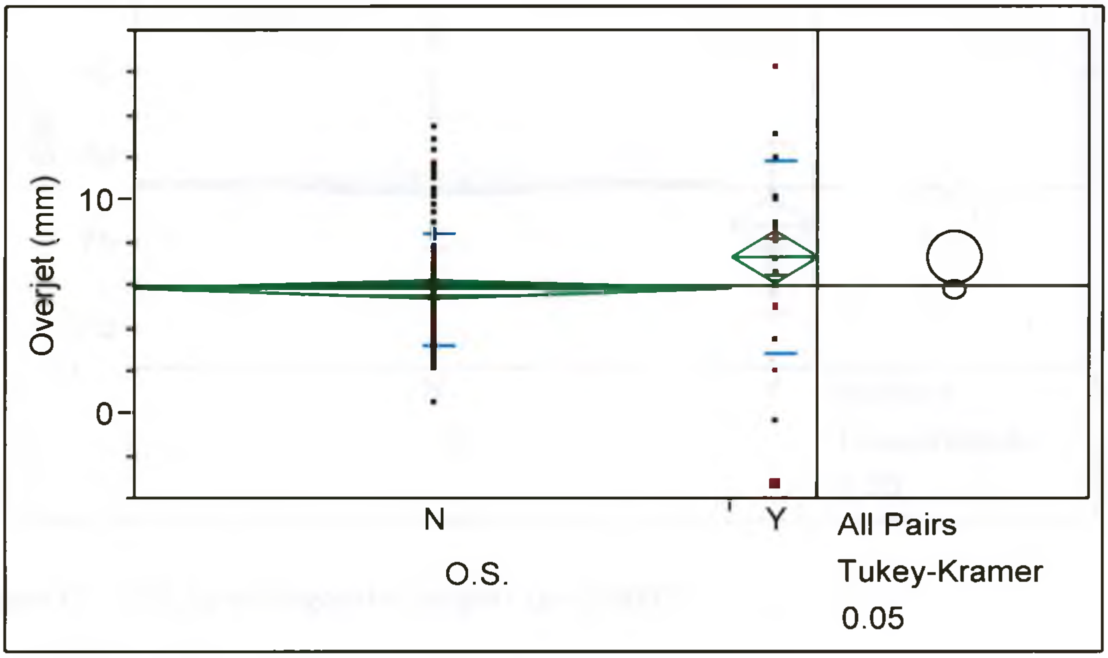


Figure 65. Overjet by orthognathic surgery (p=0.0236).

Oneway Analysis of U1-PP By O.S.

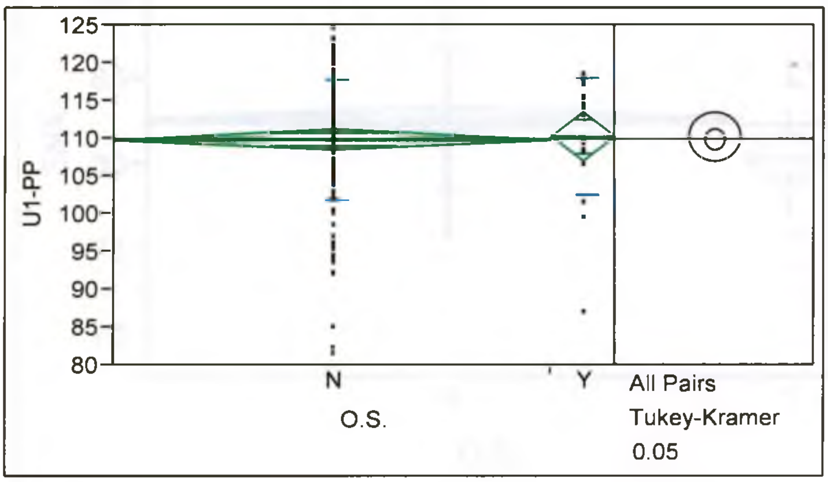


Figure 66. U1-PP by orthognathic surgery (p= 0.8292)

Oneway Analysis of SNB By O.S.

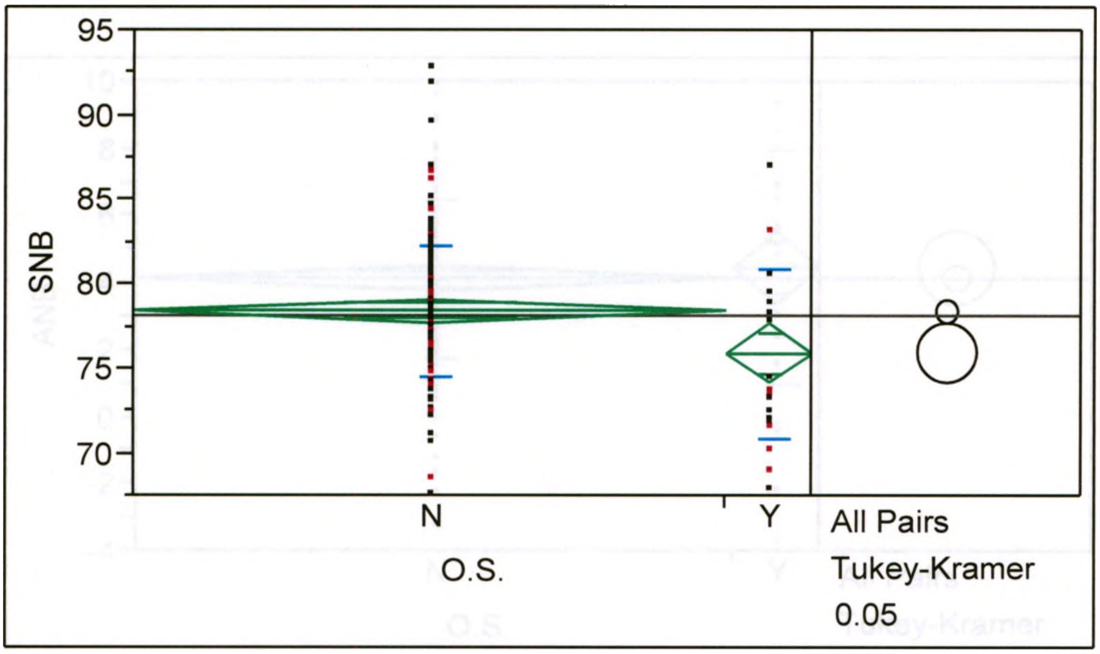


Figure 67. SNB by orthognathic surgery (p= 0.0003).

Oneway Analysis of SNA By O.S.

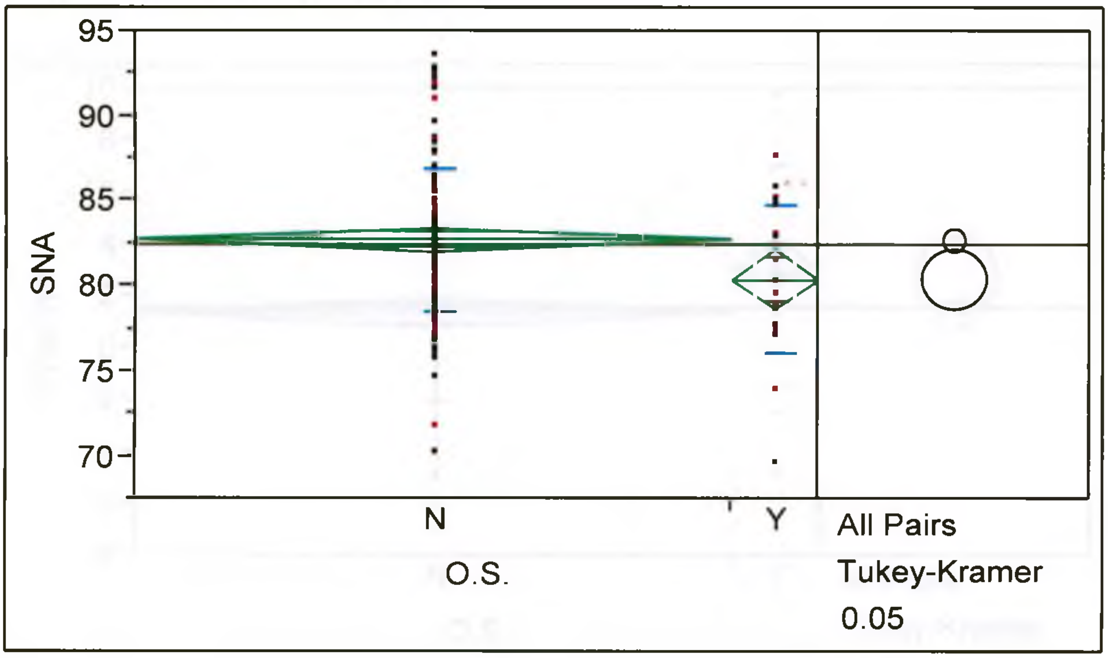


Figure 68. SNA by orthognathic surgery (p= 0.0171).

Oneway Analysis of ANB By O.S.

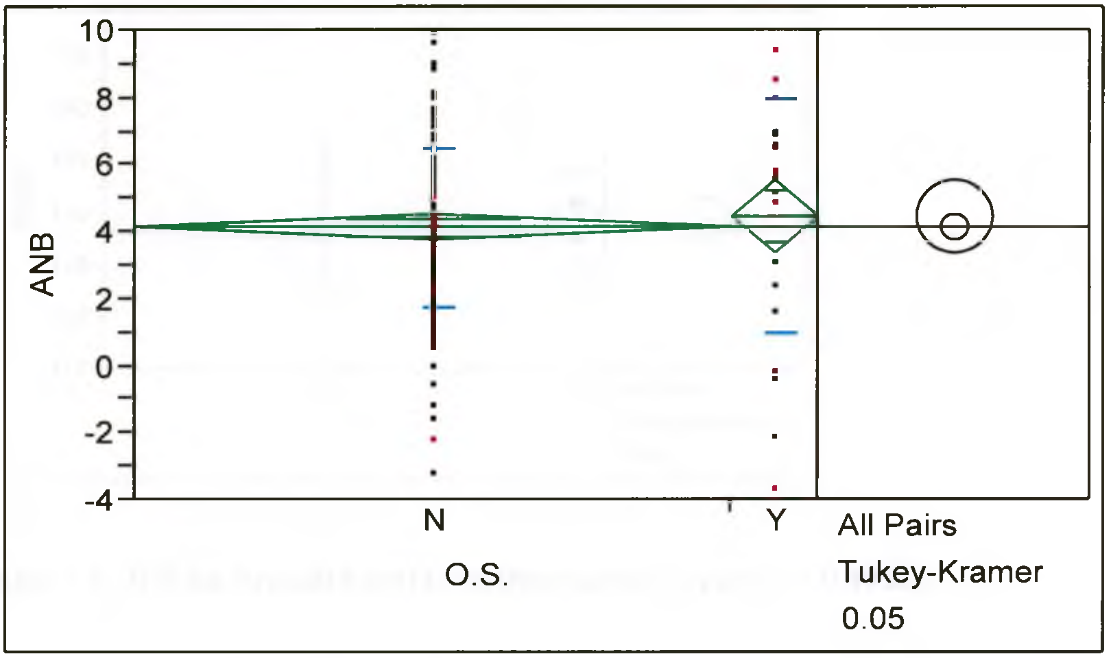


Figure 69. ANB by orthognathic surgery (p= 0.5758).

Oneway Analysis of Wits (mm) By O.S.

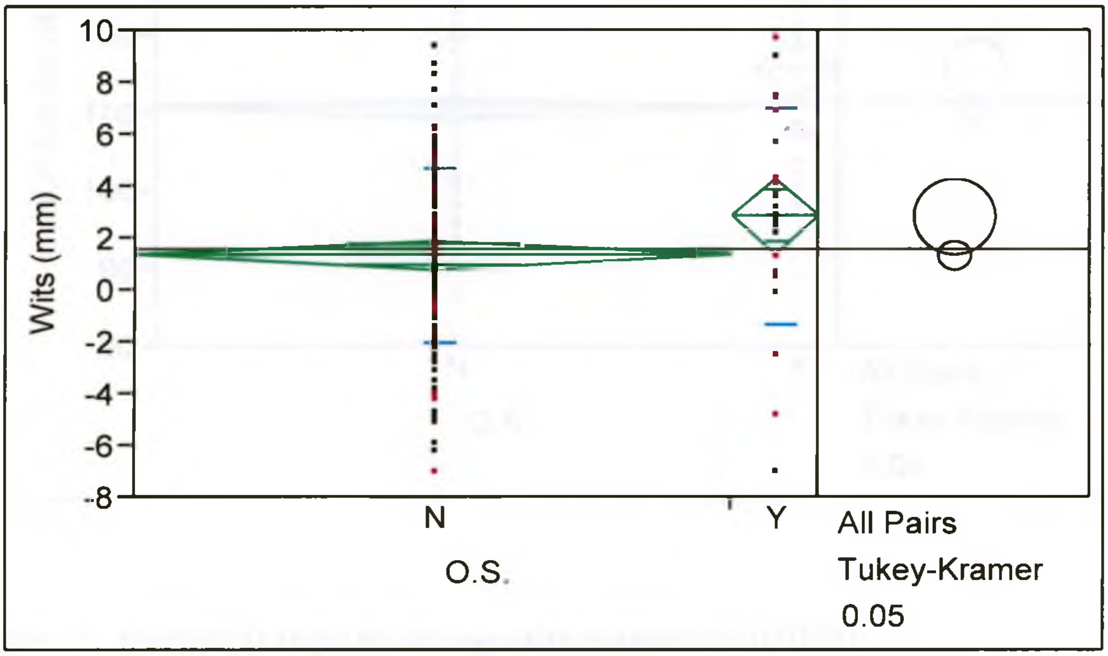


Figure 70. Wits by orthognathic surgery (p= 0.0552).

Oneway Analysis of SN-Ba By O.S.

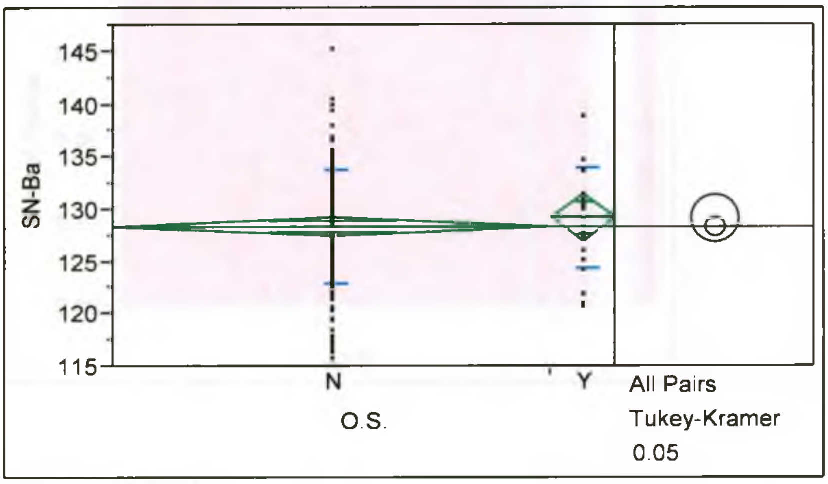


Figure 71. N-S-Ba (cranial base) by orthognathic surgery (p= 0.4836).

Oneway Analysis of NLA Col-Sn-UL By O.S.

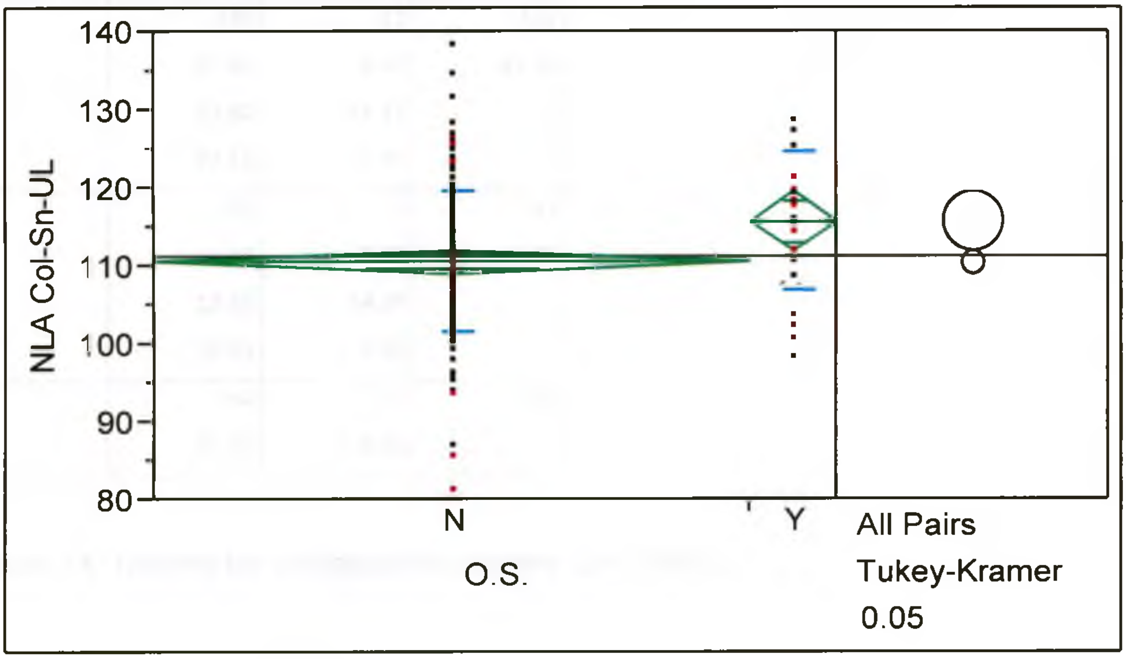
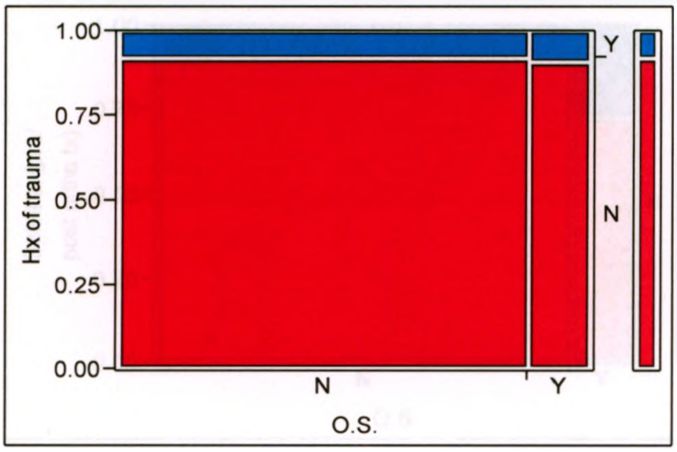


Figure 72. Nasolabial angle by orthognathic surgery (p= 0.0126).

Contingency Analysis of Hx of trauma By O.S.



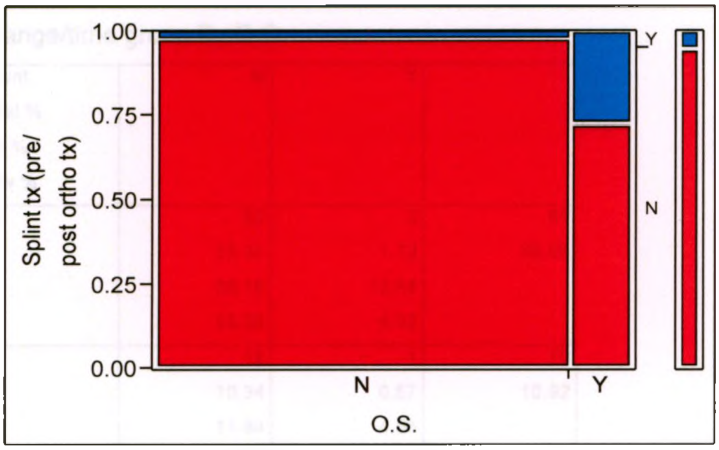
Contingency Table

O.S. By Hx of trauma

Count Total % Col % Row %	N	Y	
N	140 80.46 87.50 92.11	12 6.90 85.71 7.89	152 87.36
Y	20 11.49 12.50 90.91	2 1.15 14.29 9.09	22 12.64
	160 91.95	14 8.05	174

Figure 73. Trauma by orthognathic surgery (p= 0.8495).

Contingency Analysis of Splint tx (pre/post ortho tx) By O.S.



O.S. By Splint tx (pre/post ortho tx)

Count Total % Col % Row %	N	Y	
N	149 85.63 90.30 98.03	3 1.72 33.33 1.97	152 87.36
Y	16 9.20 9.70 72.73	6 3.45 66.67 27.27	22 12.64
	165 94.83	9 5.17	174

Figure 74. Splint therapy by orthognathic surgery (p= <0.0001).

Contingency Analysis of Change over Time by Orthognathic Surgery

change/time group By O.S.

Count Total % Col % Row %	N	Y	
A	58 33.33 38.16 95.08	3 1.72 13.64 4.92	61 35.06
B	18 10.34 11.84 94.74	1 0.57 4.55 5.26	19 10.92
C	19 10.92 12.50 95.00	1 0.57 4.55 5.00	20 11.49
D	2 1.15 1.32 100.00	0 0.00 0.00 0.00	2 1.15
E	18 10.34 11.84 69.23	8 4.60 36.36 30.77	26 14.94
F	0 0.00 0.00 0.00	1 0.57 4.55 100.00	1 0.57
G	5 2.87 3.29 100.00	0 0.00 0.00 0.00	5 2.87
H	12 6.90 7.89 85.71	2 1.15 9.09 14.29	14 8.05
I	1 0.57 0.66 100.00	0 0.00 0.00 0.00	1 0.57
J	5 2.87 3.29 83.33	1 0.57 4.55 16.67	6 3.45
L	3 1.72 1.97 75.00	1 0.57 4.55 25.00	4 2.30
N	7 4.02 4.61 70.00	3 1.72 13.64 30.00	10 5.75
O	0 0.00 0.00 0.00	1 0.57 4.55 100.00	1 0.57
S	3 1.72 1.97 100.00	0 0.00 0.00 0.00	3 1.72
T	1 0.57 0.66 100.00	0 0.00 0.00 0.00	1 0.57
Total Count Total %	152 87.36	22 12.64	174

Figure 75,76. Association of condylar change over time by orthognathic surgery.

Catagories for change over time A-U:

A. 0-0
B. 0-1
C. 0-2
D. 0-2.5
E. 0-3
F. 0-4
G. 1-1
H. 1-2
I. 1-2.5
J. 1-3
K. 1-4
L. 2-2
M. 2-2.5
N. 2-3
O. 2-4
P. 2.5-2.5
Q. 2.5-3
R. 2.5-4
S. 3-3
T. 3-4
U. 4-4

Figure 77. Catagories for condylar change over time.

Appendix I

TMJ Condylar Assessment Score

TMJ condylar scoring was based on a system outlined and utilized by Helenius et al. Examples of gradings are demonstrated in the diagram below as per Helenius et al. They designated grade 0 as no erosion of the condylar head, grade 1 as very slight erosion (Figure 1 A), grade 2 as erosion of the top of the condyle (Figure 1 B), grade 3 as erosion of half of the condyle (Figure 1 C), and grade 4 as complete erosion of condyle (Figure 1 D).

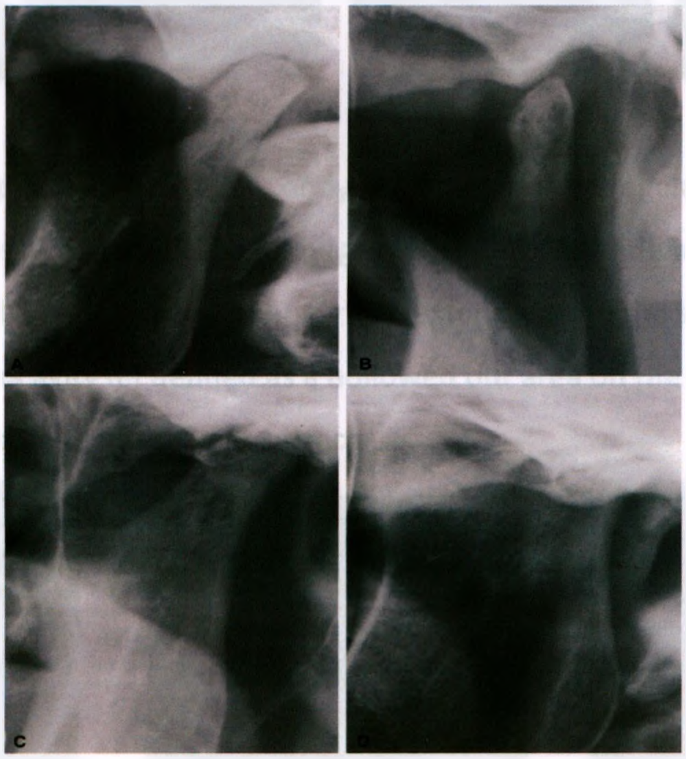


Figure 1. Condylar assessment score guide

Scores of 0 to 2 were considered to be mild, scores of 2 with subdivisions or 3 were considered to be moderate, and scores of 4 were considered to be severe bony condylar changes. For examples of condyle assessment scores are demonstrated below.

Examples of condyle assessment score of subjects from our study




Grade 1 Grade 2 Grade 3 Grade4

Subdivisions were also added mainly for condylar surfaces with irregularities. These included: osteophyte (a) defines as a marginal bony outgrowth, sclerosis (b) defines as a local area with increased density of the cortical bony joint surface extending into the subcortical bone, and irregular border or concavity (c) defined as a hollowed out area on the bony contour with a well-defined cortical outline of the joint surface.



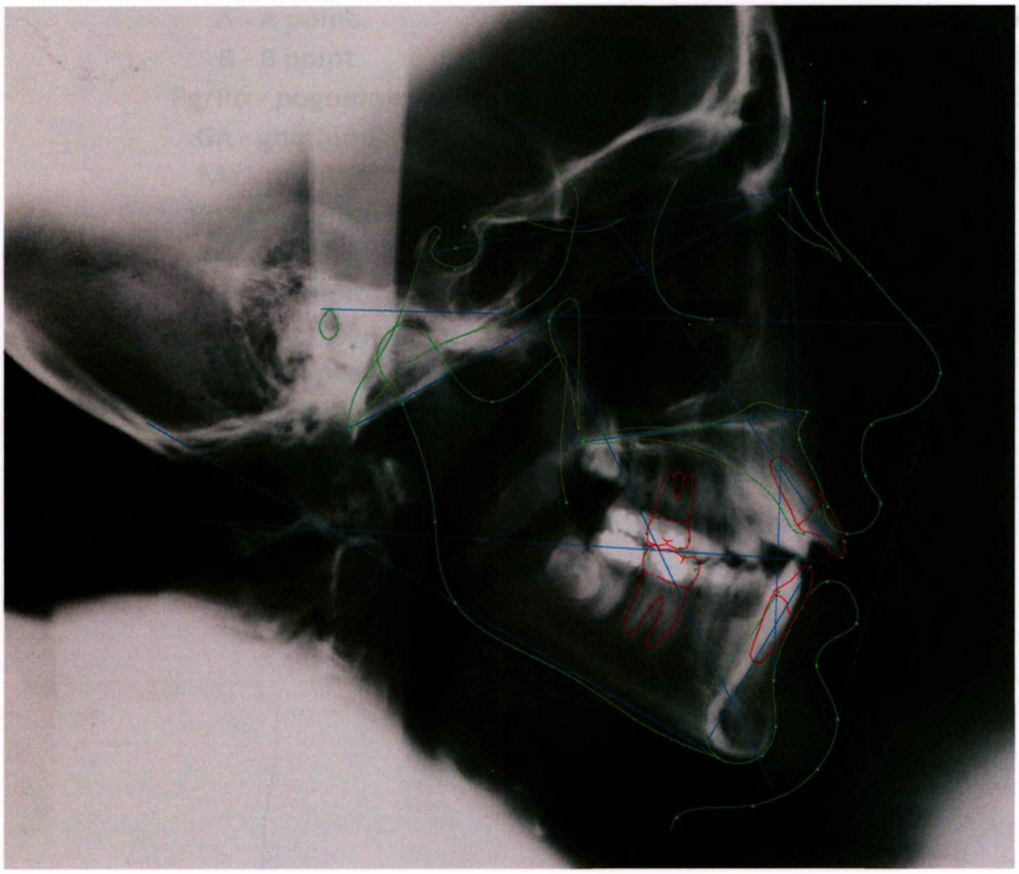
OSTEOPHYTE (a) SCLEROSIS (b) IRREGULAR BORDER (c)

Figure 2, 3, and 4. Condylar assessment score subdivisions

If a subject was assigned a grade of 2 with a subdivision (a, b, or c), grade 3, or grade 4, there were to be included in the sample. Scoring of all sample subjects was done by one examiner. When a subject had a score that was borderline between 2 or 3, a second examiner was consulted.

Appendix II

Cephalometric Study



Cephalometric Points Used

Na - nasion
S - sella
Ba - basion
Or - orbitale
P - porion
A - A point
B - B point
Pg/Po - pogonion
Gn - gnathion
Me - menton
Co - condylion
Ar - articulare
Go - gonion
ANS - anterior nasal spine
PNS - posterior nasal spine
Ptm - pterygomaxillary fissure

Cephalometric Lines used

Frankfurt Horizontal (FH) P-Or
Sella-Nasion (SN)
Occlusal Plane (OP)
Mandibular Plane (MP) - line tangent to lower border of mandible
Palatal Plane (PP) - ANS to PNS
Upper incisor angulation (U1)
Lower incisor angulation (L1)
E Plane - line tangent to tip of nose and lower lip
Nasion-A point perpendicular
Nasion-Pogonion perpendicular

Appendix III

Error Study

The cephalometric radiographs of 33 subjects were randomly selected from the sample and retraced about 6 months after the initial tracing on Dolphin Imaging 10.0. All 43 cephalometric measurements were selected to include as many landmarks as possible. Differences were then calculated between the original and retraced measurements. The measurement error of the original measurements and difference between the original and the retraced measurements was then calculated. The following formula was then used to calculate the intra-class correlation coefficient for each of the eight measurements:

ICC (R) = measurement error (original) – measurement error (difference)/measurement error (original)

MEASUREMENT	Mean Difference	ICC (R) equation	R
U1-SN (deg)	1.029	(87.36-3.82)/87.36	0.96
U1-NA (deg)	0.4226	(89.29-2.27)/89.29	0.97
U1-NA (mm)	0.5064	(11.27 -0.58)/11.27	0.95
U1-L1 (deg)	0.1064	(165.96-3.42)/165.96	0.98
L1-Apo (mm)	0.2774	(7.18-0.13)/7.18	0.98
IMPA (L1-MP) (deg)	0.3323	(67.71-1.689)/67.71	0.98
Overbite (mm)	0.0548	(10.03-.13)/10.03	0.99
Overjet (mm)	0.1548	(5.426-.1687)/5.426	0.97
UFH (N-ANS/ (N-ANS +ANS-ME)) (%)	-0.1839	(7.587-.3169)/7.587	0.96
LFH (ANS-Me/(N-ANS+ANS-Me)) (%)	0.1839	(7.127-.3218)/7.127	0.95
LFH/TFH (%)	0.1097	(.7-.0696)/.7	0.90
SNA	0.3741	(19.37-.77)/19.37	0.96
SNB	0.571	(16.26-.5034)/16.26	0.97
ANB	-0.1483	(8.059-.2684)/8.059	0.97
Mx skeletal (A-Na Perp) (mm)	-0.4258	(8.566-.83550/8.566	0.90

Mn Skeletal (Pg-Na Perp) (mm)	-0.1645	(29.09-2.12)/29.09	0.93
Wits	-0.3097	(10.59-.5731)/10.59	0.95
Mx Length (Co-A) (mm)	-0.4226	(26.38-.8873)/26.38	0.96
Mn Length (Co-Gn) (mm)	0.4484	(56.987-.992)/56.987	0.98
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	0.2839	(43.068-1.18)/43.068	0.97
Facial Angle (FH- Npo)	-0.2032	(7.703-.526)/7.703	0.93
Convexity (A-Npo) (mm)	-0.3548	(8.306-.309)/8.306	0.96
Ramus Height (Ar-Go)	0.8258	(17.79-2.148)/17.79	0.88
Palatal Plane inclination	-0.2483	(12.615-.776)/12.615	0.94
Cranio-Mx Base/SN-Palatal Plane	-0.5903	(16.434-1.045)/16.434	0.94
Palatal-Occ Plane (PP-OP) (deg)	0	(12.377-1.475)/12.377	0.88
Palatal-Mn Angle (PP-MP) (deg)	-0.3161	(30.324-.892)/30.324	0.97
Occ Plane to FH	0.1419	(13.369-1.198)/13.639	0.91
Occ Plane to SN	-0.5742	(13.161-1.074)/13.161	0.92
FMA (MP-FH)	-0.1548	(23.245-.7942)/23.245	0.97
MP-SN (deg)	-1.1516	(24.405-1.186)/24.405	0.95
Gonial/Jaw Angle (Ar-Go-Me)	0.1903	(47.894-2.474)/47.894	0.95
Ar-Go-Gn	-0.2129	(30.233-1.44)/30.233	0.95
Facial Axis (Ba-Na^Pt-Gn) (deg)	0.6032	(8.758-.8634)/8.758	0.9
Y-Axis -- Downs (SGn-FH)	0.2774	(9.55-.4692)/9.55	0.95
Y-Axis -- (SGn-SN)	-0.4451	(11.22-.5329)/11.22	0.95
Anterior Face Height (NaMe) (mm)	-0.5677	(41.532-.751)/41.532	0.98
Posterior Face Height (S-Go) (mm)	1.1935	(29.237-1.719)/29.237	0.94
P-A Face Height(S-Go/N-Me) (%)	1.3451	(15.71-1.95)/15.71	0.88
Nasolabial Angle (Col-Sn-UL) (deg)	-1.3194	(86.70-17.27)/86.70	0.8
Lower Lip to E-Plane (mm)	0.0161	(8.366-.1744)/8.366	0.98
U1-Palatal Plane (deg)	0.1806	(69.249-1.544)-69.249	0.98
Ba-S-N (deg)	-0.3742	(35.122-1.155)/35.122	0.96
Articular Angle (S-Ar-Go)	-0.1806	(50.139-3.82)/50.139	0.92

The 43 ICC's were then added together and divided by 43 to achieve the mean ICC. The mean ICC or R for this study was calculated to be 0.966. This can be interpreted as a 97% agreement between the original and retraced measurements. For orthodontic cephalometric studies, and R of at least 0.9 is considered desirable.

Appendix IV

Condylar Assessment Score by Subject

Subject	Initial (T1)		Deband (T2)		R +2 (T3)	
	Left	Right	Left	Right	Left	Right
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	1	0	2	0
9	0	0	0	0	0	0
10	1	0	1	0	2	1
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	2	0	2
14	0	0	0	0	0	0
15	0	0	0	1	0	2
16	0	0	2	0	2	0

17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	1	0	2
25	0	1	0	1	0	2
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	1	0
29	0	0	1	1	1	1
30	0	0	1	1	2	1
31	0	0	1	1	1	1
32	0	0	0	0	1	1
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	0	0	0	0	0	0
36	0	1	0	2	0	2
37	0	0	0	0	0	0

38	0	0	0	0	0	0
39	0	0	0	0	0	0
40	2	0	2	0	2	0
41	0	0	2	0	2	0
42	1	0	1	0	1	0
43	1	1	2	2	2	2
44	0	1	0	1	2	2
45	0	0	1	0	1	0
46	0	0	0	0	0	0
47	0	0	0	0	0	0
48	0	0	0	0	1	0
49	1	0	1	0	1	0
50	0	0	0	0	0	0
51	1	0	1	0	2	0
52	0	0	0	0	0	0
53	0	0	0	0	0	0
54	0	1	0	1	0	1
55	0	0	0	0	0	0
56	0	0	0	0	0	0
57	0	0	0	0	2	2
58	0	0	0	0	0	0

59	0	0	1	1	1	1
60	0	0	0	0	0	0
61	0	1	0	1	0	2
62	0	0	0	0	0	0
63	0	0	0	0	0	0
64	0	0	0	0	0	0
65	0	0	0	0	0	0
66	0	2	0	2	0	2
67	0	0	0	0	1	0
68	0	0	0	0	0	0
69	0	0	0	0	2	0
70	0	0	0	0	1	0
71	0	0	0	0	0	0
72	0	0	1	0	2	0
73	0	1	0	1	0	1
74	0	0	0	0	0	0
75	0	0	0	0	0	0
76	0	0	0	0	0	0
77	0	0	1	0	2	0
78	0	0	1	1	1	1
79	0	0	0	0	0	0

80	0	0	0	0	0	0
81	2	0	2	0	2	0
82	0	0	0	0	0	0
83	0	0	0	0	0	0
84	0	0	1	1	1	1
85	0	0	0	0	1	0
86	0	0	0	0	0	0
87	0	0	0	0	0	0
88	0	0	0	1	0	1
89	0	0	0	0	0	0
90	0	1	0	2	0	2
91	0	0	0	0	0	0
92	0	0	2	0	2	0
93	0	0	0	0	0	0
94	0	0	0	0	0	0
95	0	1	0	2	0	2
96	0	0	1	2	2	2
97	1	0	1	0	2	0
98	0	0	0	0	0	1
99	0	0	0	0	0	0
100	1	0	2	0	2	0

101	0	0	0	0	0	0
102	0	0	0	0	0	0
103	0	0	0	0	0	0
104	0	0	0	0	0	0
105	1	0	1	0	1	0
106	0	0	0	1	0	1
107	0	1	0	1	0	1
108	0	0	0	0	0	0
109	0	0	2	0	2	0
110	0	0	2	2	2	2
111	0	0	2	2	2	2
112	2	1	2	1	2	1
113	1	0	2	0	2	0
114	1	0	2	0	2	0
115	0	1	1	1	2	1
116	1	1	2	1	2	2
117	0	0	0	1	0	1
118	0	0	0	0	2	0
119	0	0	2	2	2	2
120	0	0	0	0	1	1
121	0	0	0	0	0	0

122	0	0	1	0	1	0
123	0	0	0	3	0	3
124	1	0	2	1	3	1
125	0	0	0	0	2	3
126	2	0	4	0	4	0
127	2	2	2	3	2	3
128	0	0	0	3	1	3
129	1	0	2	0	3	0
130	0	0	0	3	0	3
131	0	0	0	2	0	3
132	2	0	3	0	3	0
133	0	0	0	2c	0	3
134	0	3	0	3	0	3
135	2	3	2a	3	2a	3
136	0	0	0	3	0	3
137	0	0	0	3	0	3
138	1	1	3	1	3	1
139	0	0	0	2	0	3
140	2	2	2c	3	2c	3
141	0	0	2	0	3	0
142	0	1	0	3	0	3

143	0	0	1	0	3	0
144	0	0	0	2	0	3
145	1	0	2	0	2a	0
146	0	3	0	3	0	3
147	0	0	0	3	0	3
148	0	0	2	3	2	3
149	0	3	2	3	2	3
150	0	0	0	4	0	4
151	0	0	0	2	0	3
152	0	0	3	0	3	0
153	0	0	0	0	0	3
154	0	0	0	2	0	3
155	0	0	0	2	0	3
156	0	2	0	3	0	3
157	0	1	3	3	3	3
158	0	0	2	0	2a	0
159	2	2	3	2	3	2
160	0	0	2a	0	2a	0
161	0	0	3	0	3	0
162	0	0	0	2	2	3
163	2	2	2	3	2	3

164	0	0	0	3		
165	0	2	0	3	0	3
166	0	3	1	3	1	4
167	0	2	0	3	0	3
168	0	0	0	0	3	2
169	2	0	2	1	3	1
170	0	0	0	1	3	1
171	0	0	2	0	3	0
172	0	0	2	0	3	0
173	0	1	0	2	0	3
174	0	0	1	0	3	0

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